eRD17: DPMJetHybrid 2.0

A Tool to Refine Detector Requirements for eA in the Saturation Regime

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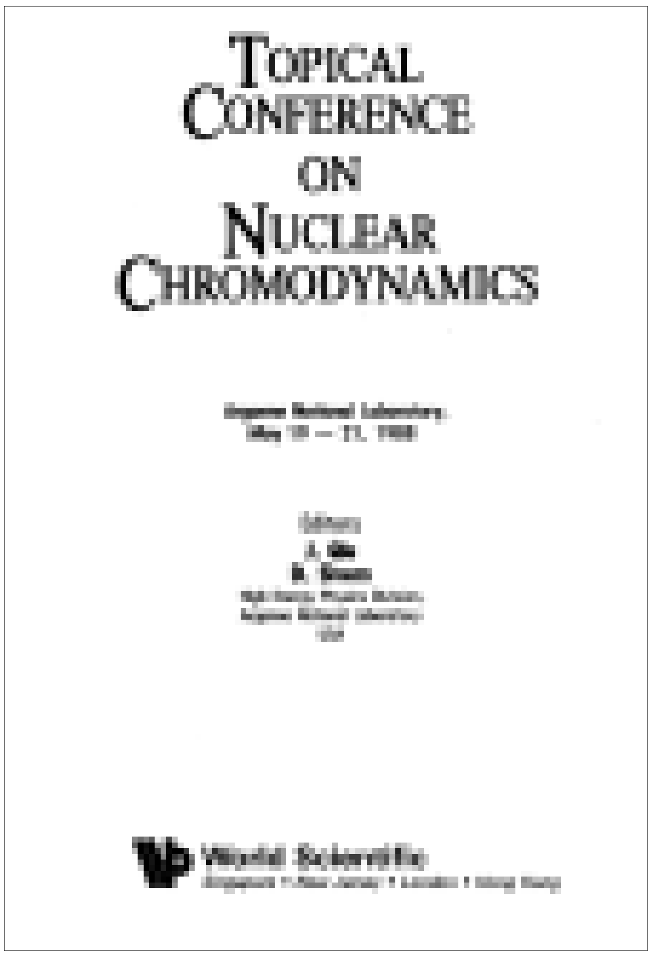
06-July-2016

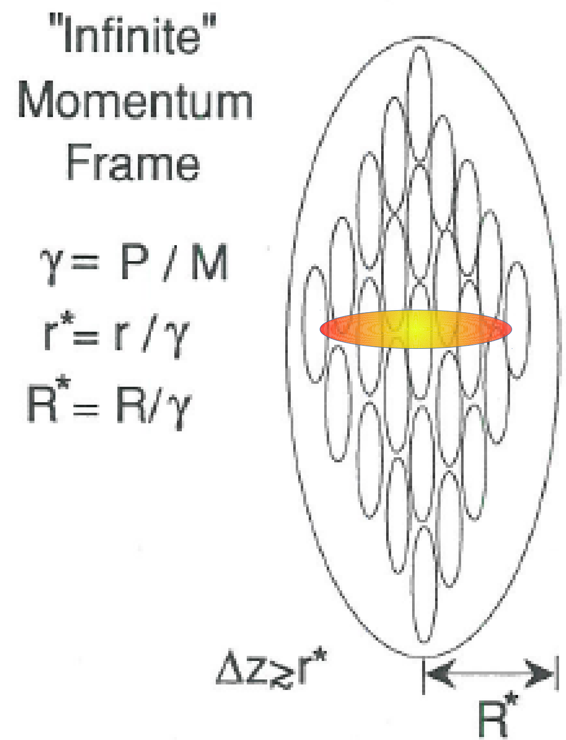
***-co-PIs**

Coming Full Circle...

1988 Conference at Argonne, (Qiu & Sivers)



Talk by Berger & Qiu



$p_z^{quark} = Mx\gamma$

$\Delta z = 1/(2Mx\gamma)$

$\Delta z/r^* = 1/(2Mxr)$
$= 0.12/x_{Bj}$

For x_{Bj}<<0.12, parton wavefunctions and/or interaction cannot be localized.

eRD17 in a nutshell

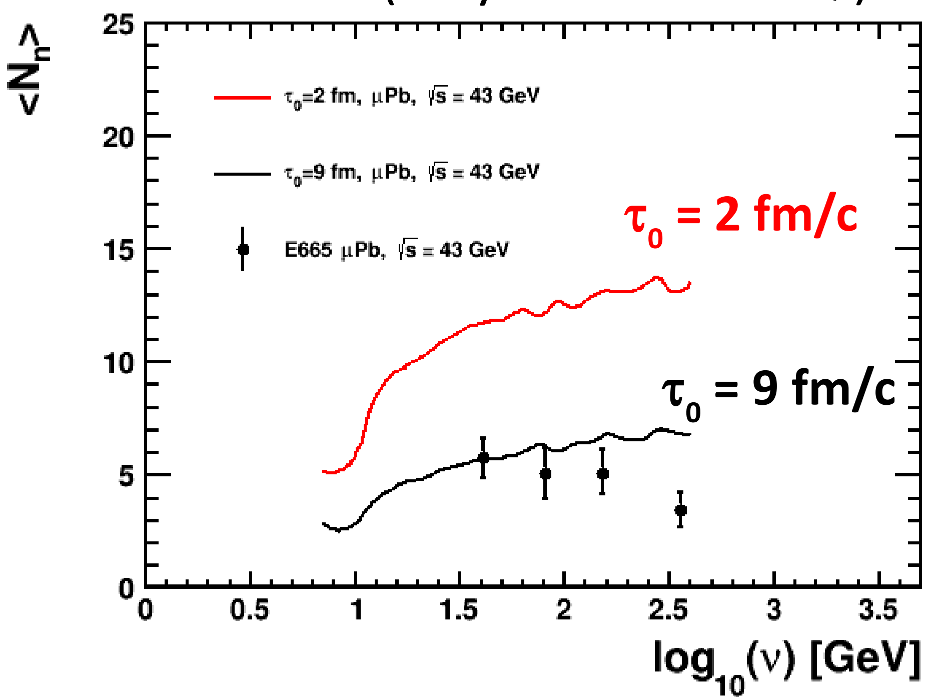
- Forward detector/IR design is happening NOW
- DIS Models for eA have a serious deficiency.
  - Missing multinucleon DIS events (shadowing).
  - We don't really know how complete the forward coverage needs to be.
- Upgrade DPMJetHybrid to include known effects
- Simulate a couple of key measurements.
  - Geometry tagging
  - Multinucleonic recoil of intrinsic k_T (aka Q_s).
- Phase I of project in FY2016: \$32,000 (=\$64k/2)
- Phase II in FY2017: \$33,000

Comparison with E665 data

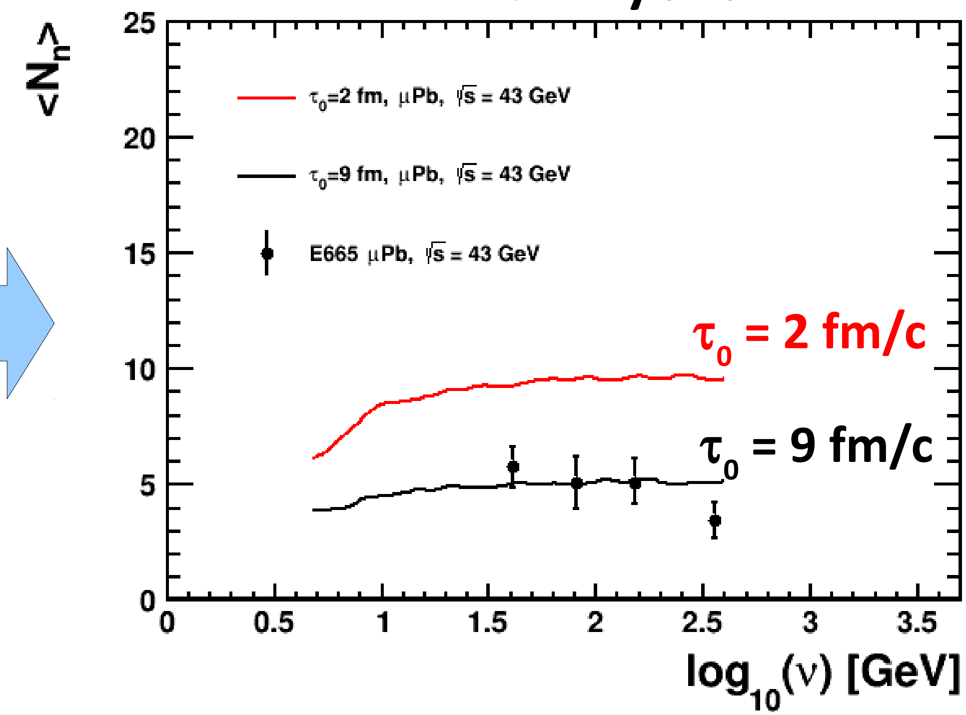
E665, PRL 74 (1995) 5198

Evaporation neutrons (E-m<10 MeV)

DPMJET (only valid at low Q^2)



DPMJETHybrid

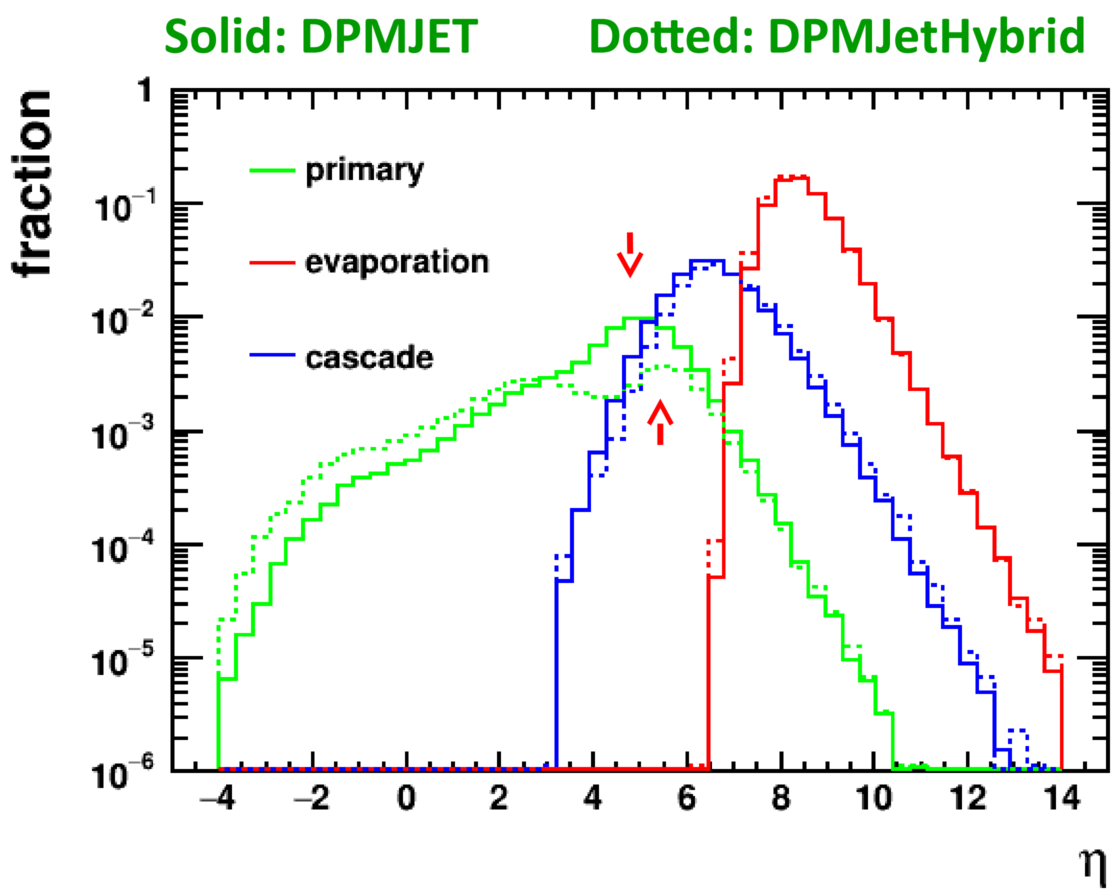


Zheng, Aschenauer, Lee,
EPJA 50 (2014) 189

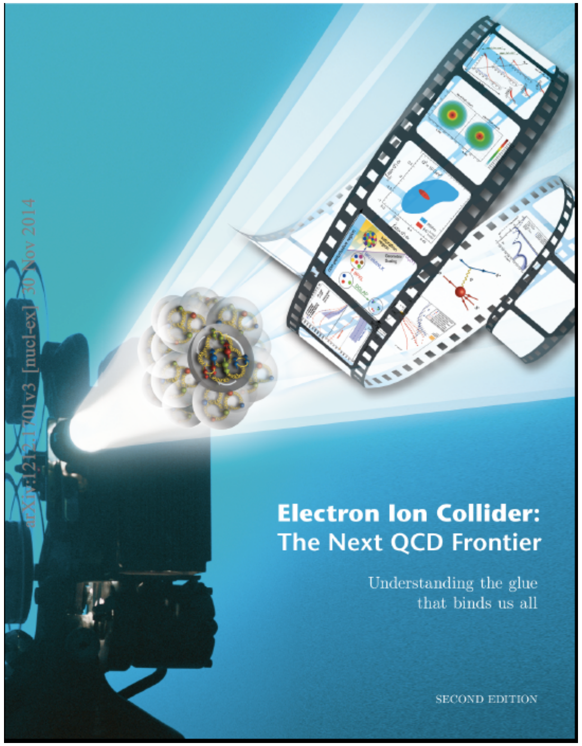
Primary Distribution

Recall from January: We were concerned about forward primary neutrons:
DPMJET primaries peaked too low in η vs. Pythia/ZEUS extrapolations.

No worries!
DPMJETHybrid works fine!



Geometry tagging physics



Chapter 3: The Nucleus: A Laboratory for QCD (p59)

Can the nucleus, serving as a color filter, provide novel insight into the propagation, attenuation and hadronization of colored quarks and gluons?

using the nucleus as a space-time analyzer the EIC will shed light on answers to the questions such as the following: How does the nucleus respond to the propagation of a color charge through it? What are the fluctuations in the spatial distributions of quarks and gluons inside the nucleus? What governs the transition from quarks and gluons to hadrons?

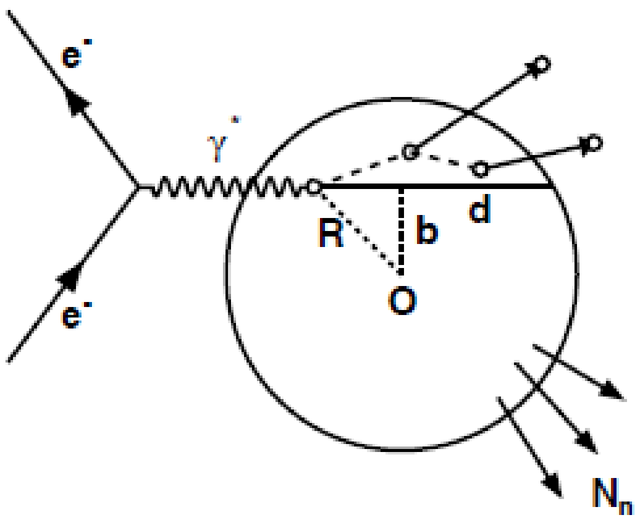
Geometry tagging is essential for this goal!

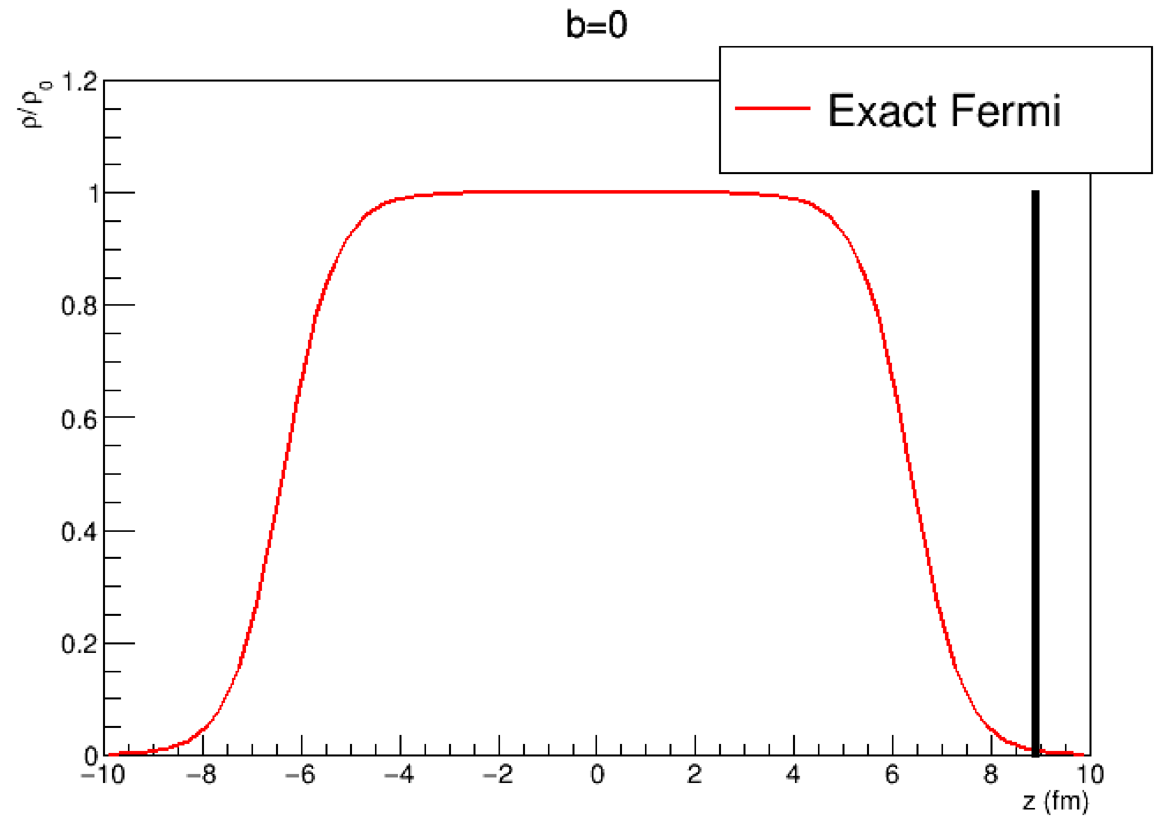
What is the role of saturated strong gluon fields, and what are the degrees of freedom in this high gluon density regime? An EIC will allow us to probe the wave functions of high-energy nuclei. By studying these interactions, one may probe the strong gluon fields of the CGC, possibly the strongest fields in nature. In …

Geometry tagging is required to address this goal with 40 GeV*A ion energies.
Further enhances saturation at 100 GeV*A ion energies.

Technical aside: Definition of "d"

Zheng, Aschenauer, Lee defined the “edge” of the nucleus to be where the density falls to 1/101 (<1%) of the maximum.





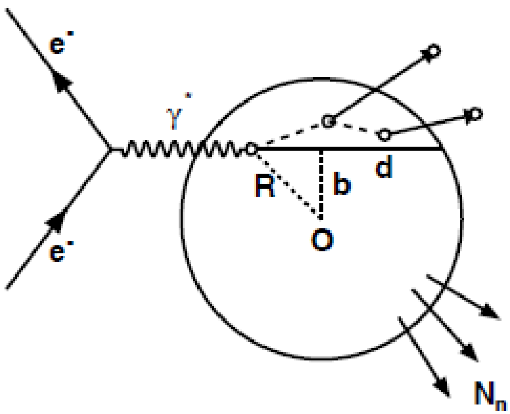
This includes 0-6 fm of empty space as part of “d”.

We will define d as:

$\boxed{\bar{d} \equiv \int dz\ \rho/\rho_0}$ w/ integral from $Z_{\text{first-collision}} \rightarrow \infty$

Note: $\bar{d} \approx R_{Au}$=6.38 fm for collision at center of nucleus.

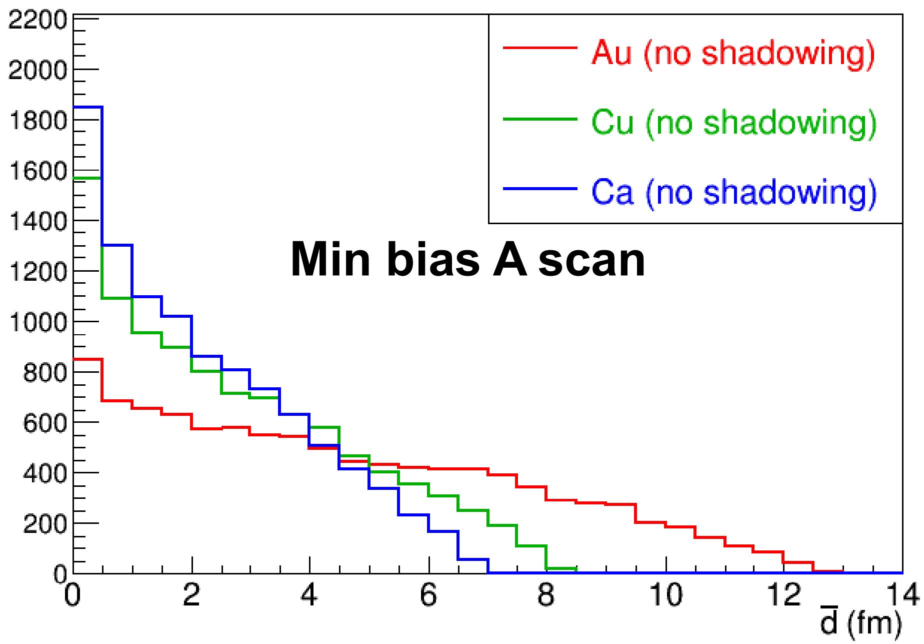
Geometry tagging (w/o shadowing)

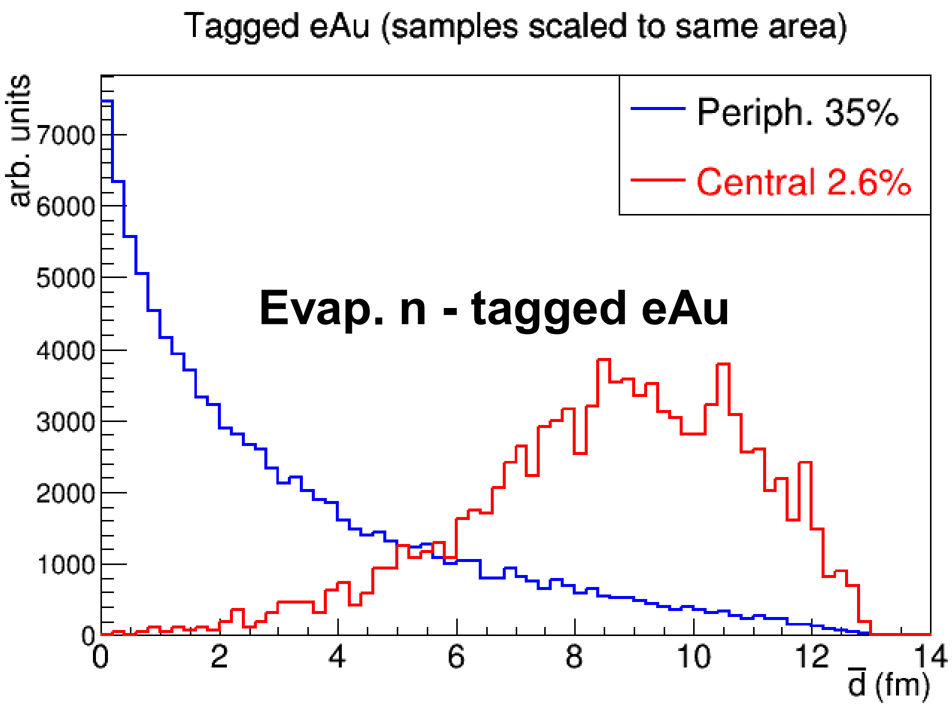


Intra-nuclear cascading increases with d (forward particle production)

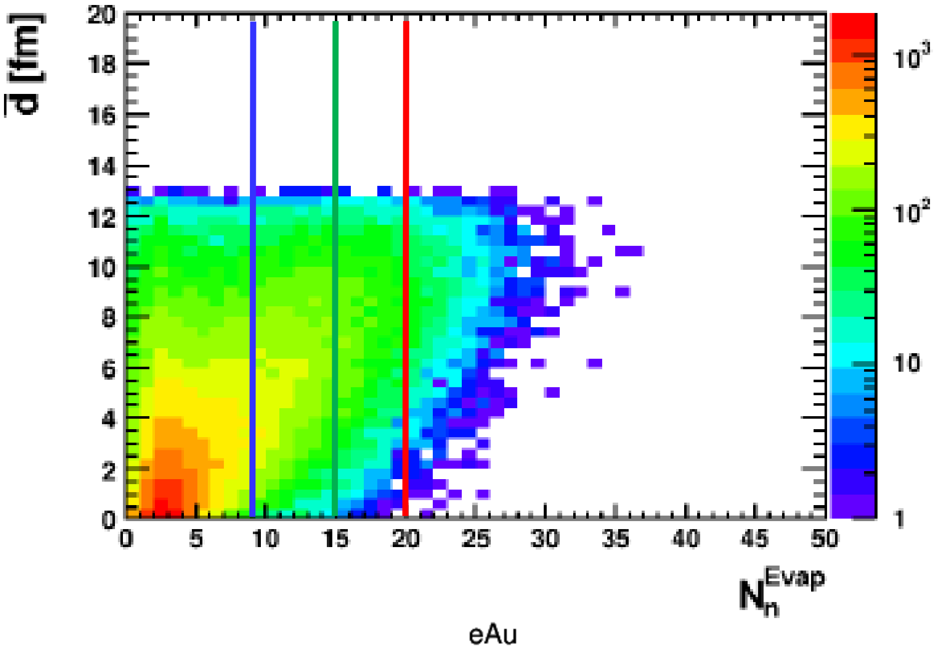
Leads to more evaporation of nucleons from excited nucleus (very forward)

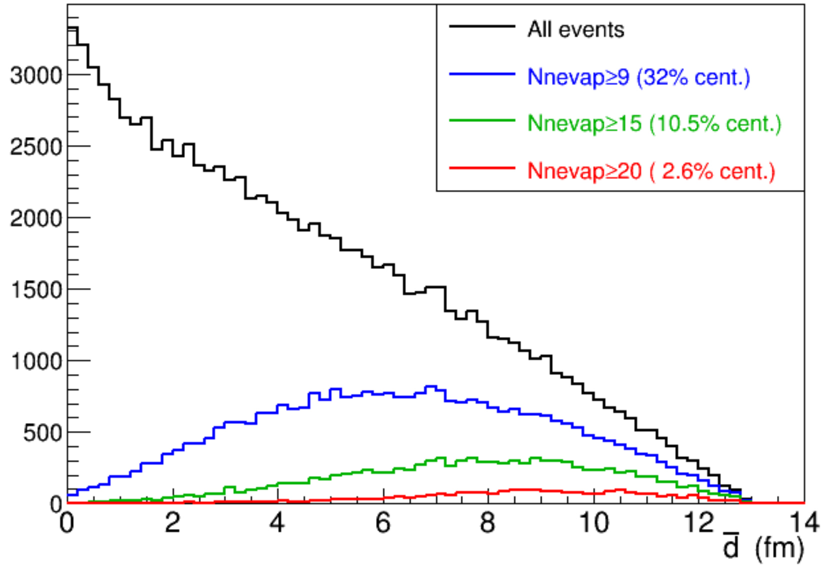
LOOKS GOOD!





Path length selection: purity vs. efficiency

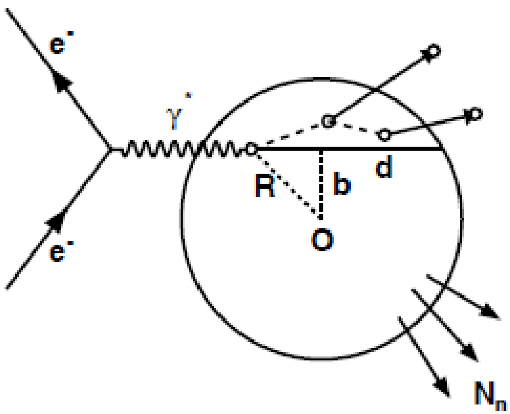




- Geometry tagging using only evaporation neutrons is already encouraging!
  - Proof of concept
  - Limitation: cut on large multiplicity is required, reducing efficiency (yield)
- How important is it to measure forward charged particles as well?
  - Multi-dimensional constraints may allow both high purity and efficiency
  - IntraNuclearCascading may allow us to infer the direction of b as well as its magnitude.
- How will tagging improve in the nuclear shadowing region (low x)?
  - Central (low b or high d) events will have multiple collisions improving our resolution.
  - Low b will have more collisions than high b, leading to a ***direct signal for low b***.

Thanks to Pawel Nadel-Turonski for input on this slide

Geometry tagging b vs. d

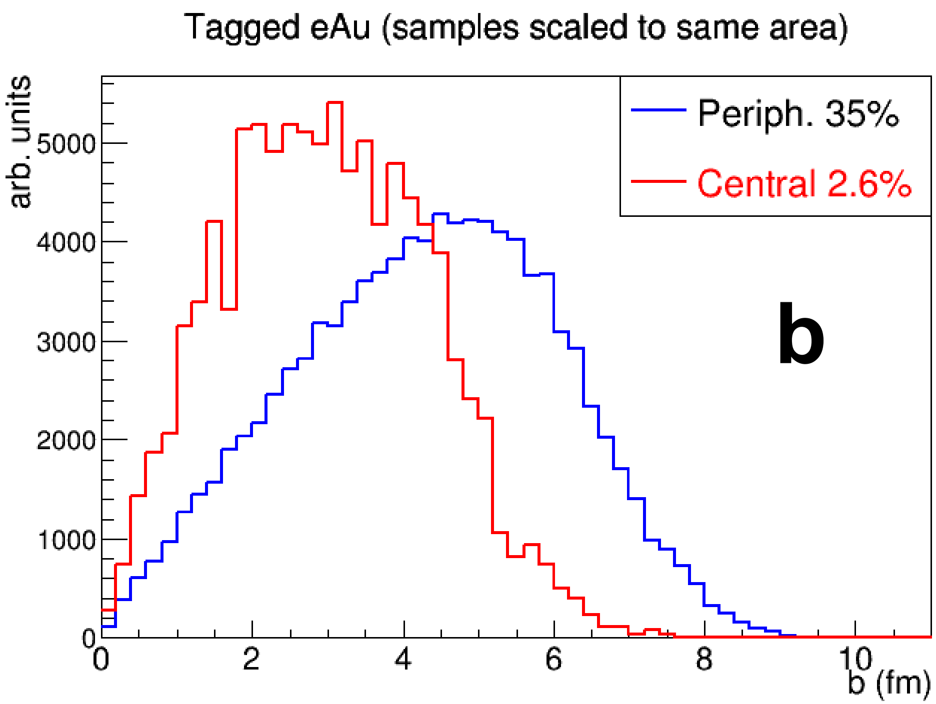


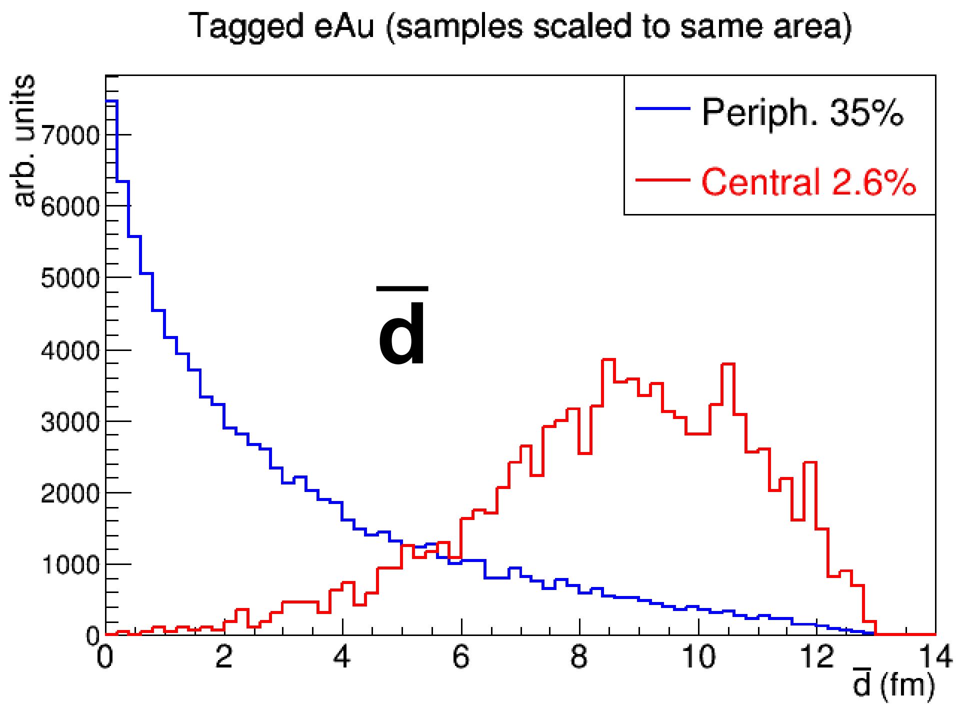
Intra-nuclear cascading increases with d (forward particle production)

Leads to more evaporation of nucleons from excited nucleus (very forward)

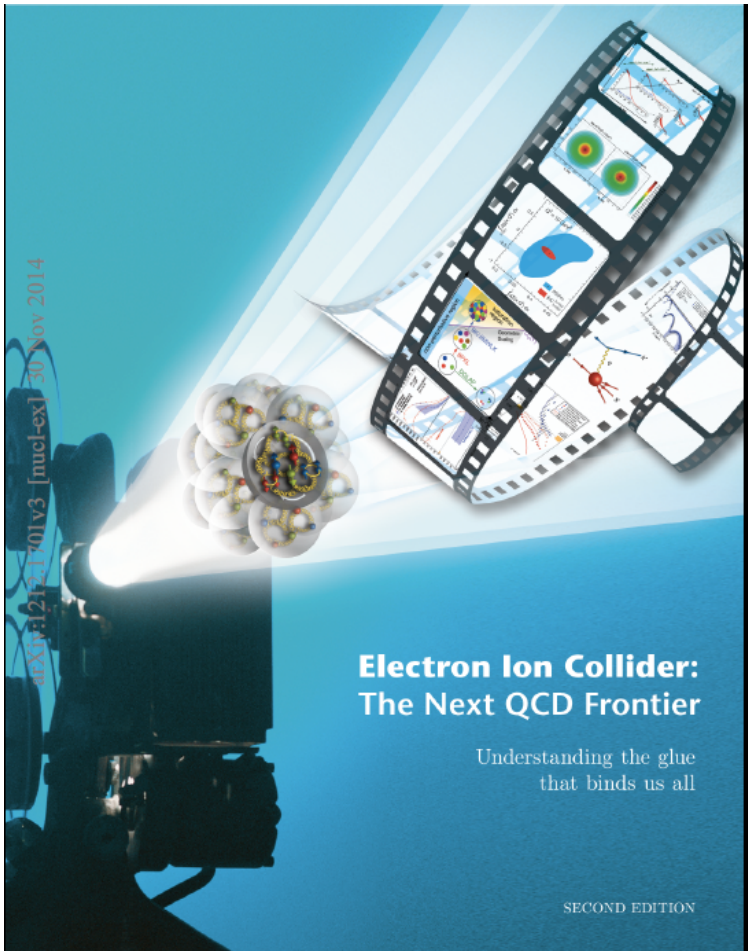
Evap. n - tagged eAu
No shadowing

b is indirectly taggable because it correlates with d.





Saturation at EIC is multi-nucleonic

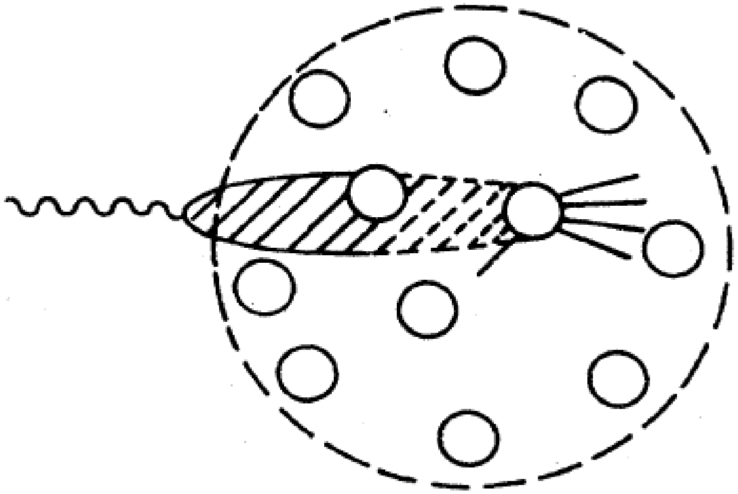


Executive Summary (page ix)

To date this saturated gluon density regime has not been clearly observed, but an EIC could enable detailed study of this remarkable aspect of matter.

This pursuit will be facilitated by electron collisions with heavy nuclei, where coherent contributions from many nucleons effectively amplify the gluon density being probed.

Basic idea of proposal



The virtual photon, in the target rest frame, can be treated as alternating between a point-like particle with σ~0 and a "dipole" or more complicated hadronic object with a larger σ (few mb). The coherence length of the "dipole" is λ~1/(2Mx). The fraction of the time it spends in this state is whatever fraction is needed for the total σ_{ep} to be correct.

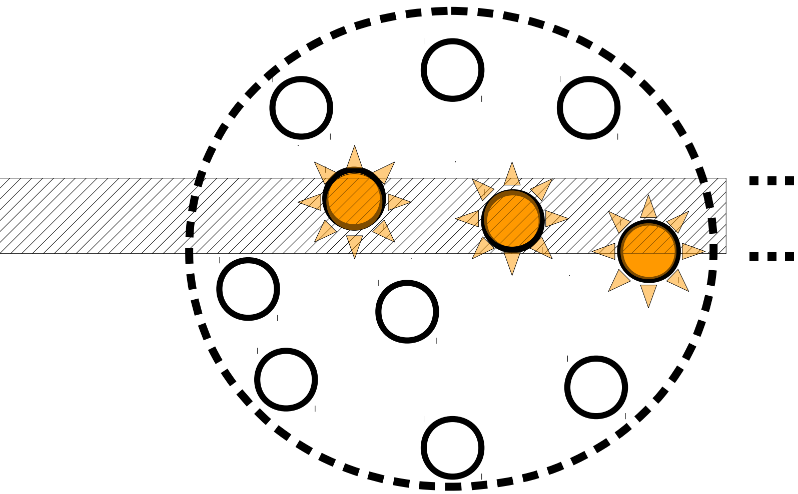
Do NOT model saturation in detail to find $\sigma_{dipole}(x,Q^2)$!

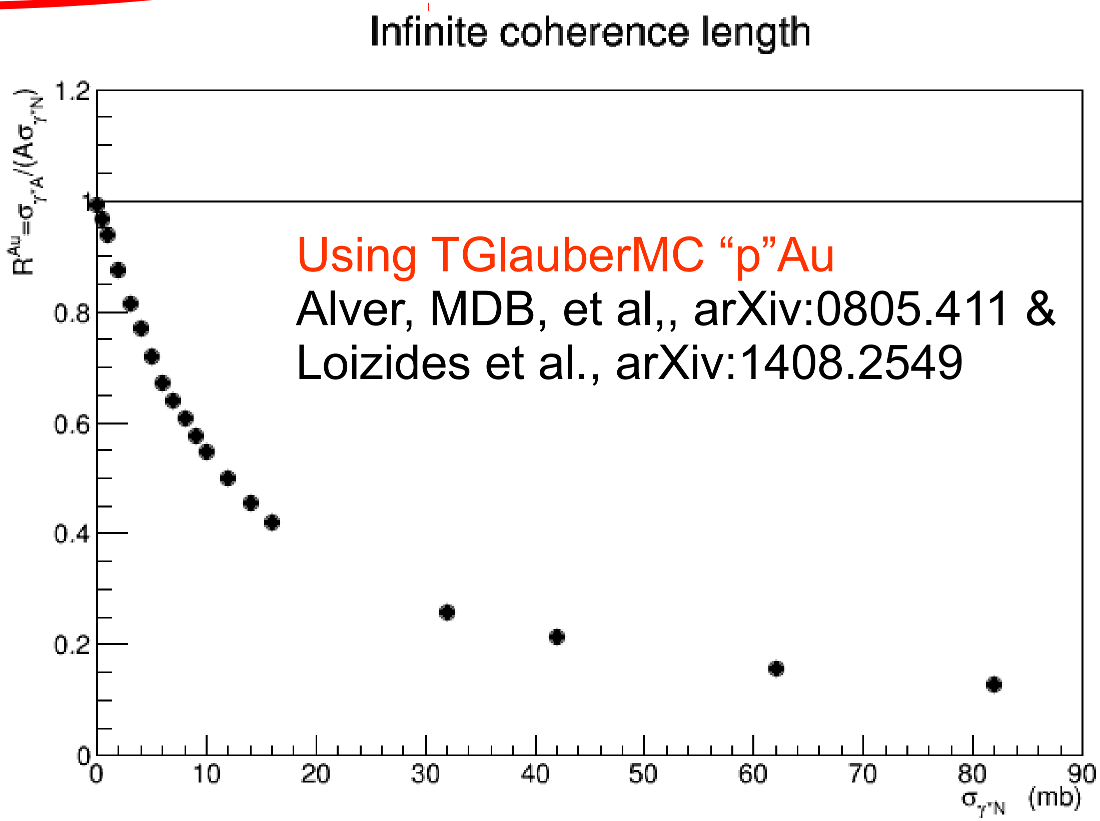
Rather, use an input value of nuclear shadowing $R^{Au}(x,Q^2)$ to find $\sigma_{dipole}(x,Q^2)$. Then model probability of multiple nucleon DIS.

Making the map for $\lambda \gg R$

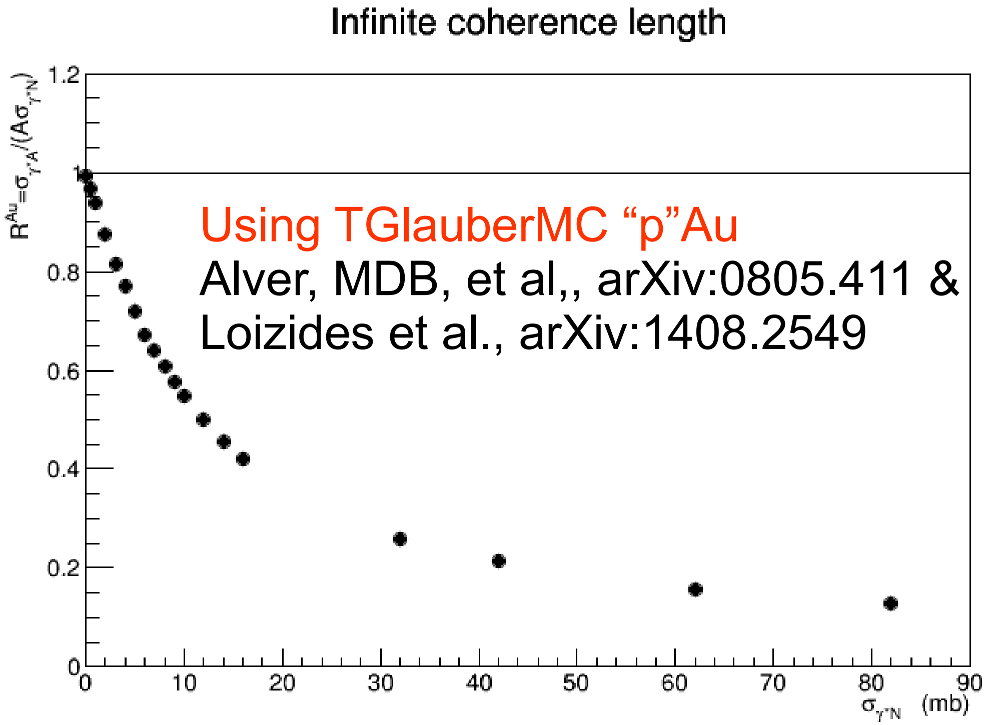
Most of the complications in saturation theory are in predicting the dependence on x, Q^2. With Glauber, we can make a simple map:

$\sigma^A/\sigma^N(x,Q^2) \Longleftrightarrow \sigma_{\text{"dipole"}}(x,Q^2) \Longleftrightarrow P(N_{coll},b)$

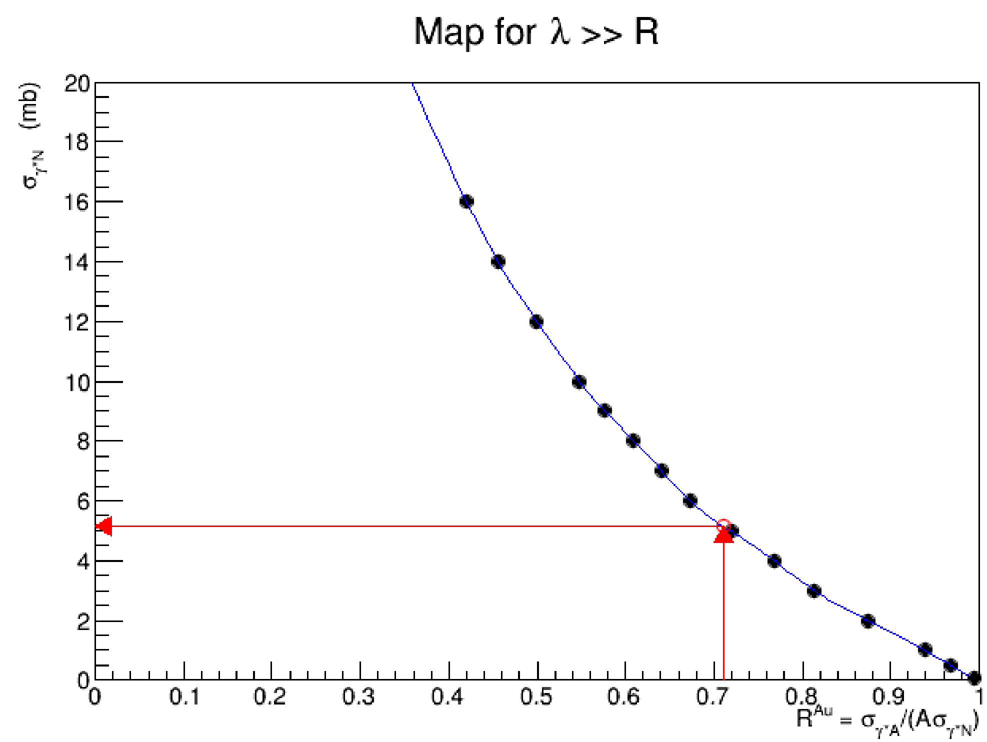




Looking up the appropriate $\sigma_{\gamma^*N}(x,Q^2)$



Flip axes to make map.



Event-by-event, given x & Q^2:

E.g. for x=0.001, Q^2=1.69 GeV^2

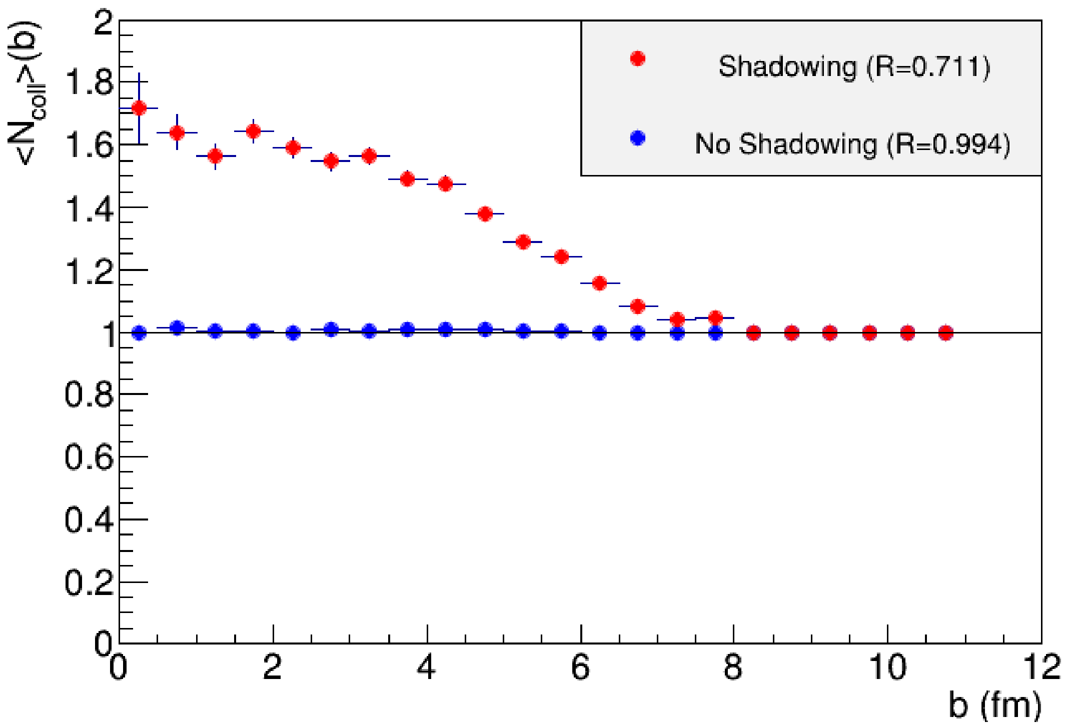
$R^{(Au/N)}(x\rightarrow 0, Q^2=1.69\,GeV^2) \approx 0.711$

$\sigma_{\text{"dipole"}}$ = 5.16 mb

$N_{coll}(b)$ for Q^2=1.69 GeV^2,x<<1

$\sigma^A/\sigma^N(x,Q^2)$ ⟷ $\sigma_{dipole}(x,Q^2)$ ⟷ $P(N_{coll},b)$

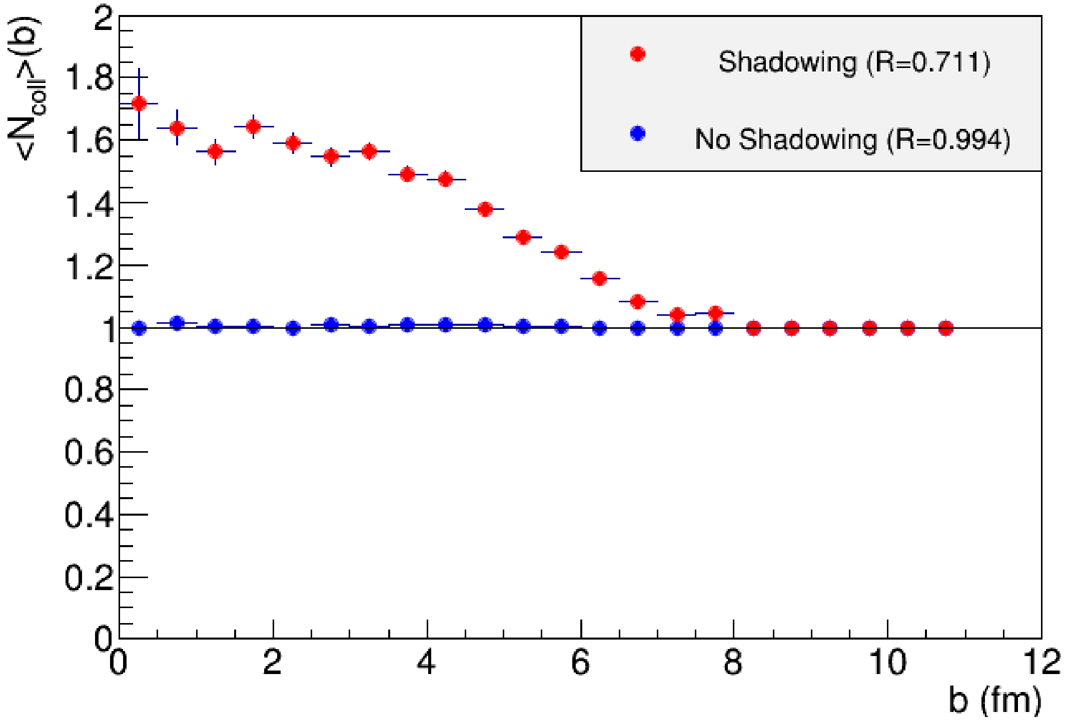
- **Big difference between b=0 & b= R_{Au}=6.38 fm at low x,Q^2**
- **Geometry tagging easier. Now b is <u>directly</u> correlated with measurable activity**



$N_{coll}(b)$ for Q^2=1.69 GeV^2,x<<1

$\sigma^A/\sigma^N(x,Q^2)$ ⟷ $\sigma_{dipole}(x,Q^2)$ ⟷ $P(N_{coll},b)$

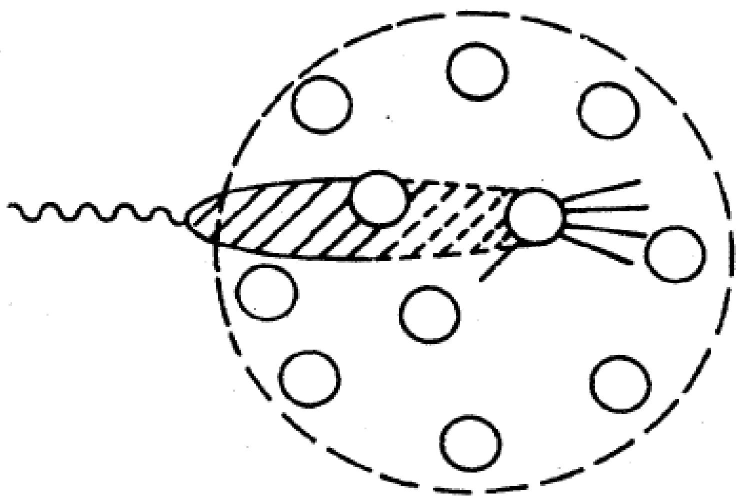
- **Big difference between b=0 & b= R_{Au}=6.38 fm at low x,Q^2**
- **Geometry tagging easier. Now b is <u>directly</u> correlated with measurable activity**
- **Enhanced shadowing (& saturation?) at b=0 (recall R=1/N_{coll}).**

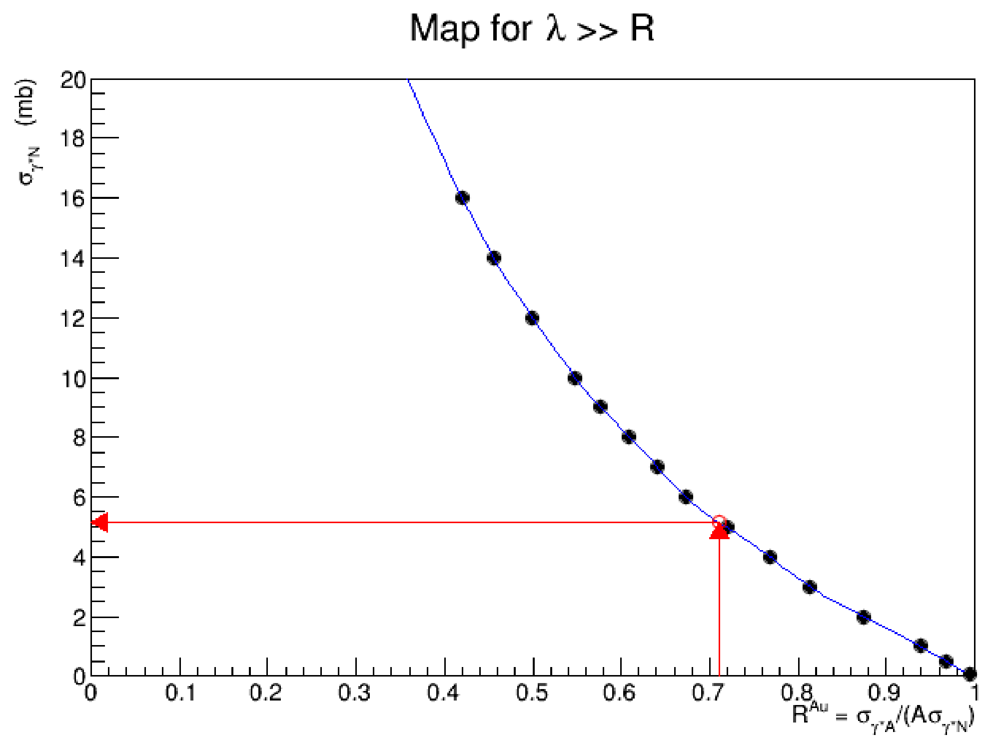


Plans for remainder of FY2016

- Implement multiple collisions in DPMJetHybrid
  - Simplification: $\lambda=0$ or $\lambda=\infty$ only.
  - Simplification: Only 1 DIS /event for now (the rest can be elastic/diffractive).
  - Released code for use at BNL, JLAB, (&...)
- Quick look
  - Physics simulations of geometry tagging.
  - Physics simulations of multinucleon k_T recoil.

FY2017: Making the map for $\lambda \sim R$





By the end of FY2016, we will have implemented $\lambda=0$ (default) & $\lambda=\infty$.

For finite λ, must modify TGlauberMC & DPMJetHybrid (again).

The map will give us $\sigma_{\text{"dipole"}}$ as a function of $R^{Au}(x,Q^2)$ & $\lambda(x)$.

FY2017 Plans

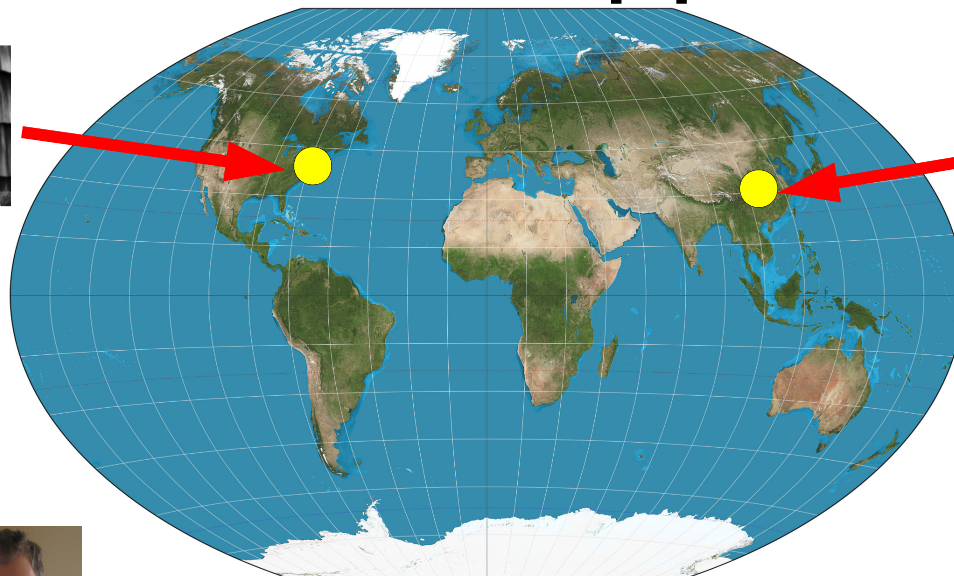
- Remove limitations from "simplified" model
  - Include intermediate values of λ (& of x_{Bj})
  - Allow multiple DIS interactions, not just 1, requiring non-trivial color connections.
- Project should be complete at end of FY2017
  - Released code for use at BNL, JLAB, (&...)
  - Physics simulations of geometry tagging.
  - Physics simulations of multinucleon k_T recoil.

Manpower & Budget

Person	Institution	Effort (FTE-year)	Cost to Proposal	Remarks
E. Aschenauer	BNL	0.05	$0	cost covered by BNL
M.D. Baker	MDBPADS[22]	0.14	$33,000	
J.H. Lee	BNL	0.05	$0	cost covered by BNL
L. Zheng	CCNU	0.10	$0	cost covered by CCNU & BNL
TOTAL:		0.34	$33,000	

Table 2: Personnel Budget Breakdown

Critical Issue:
Limited time opportunity!



FY2016

1QFY2017

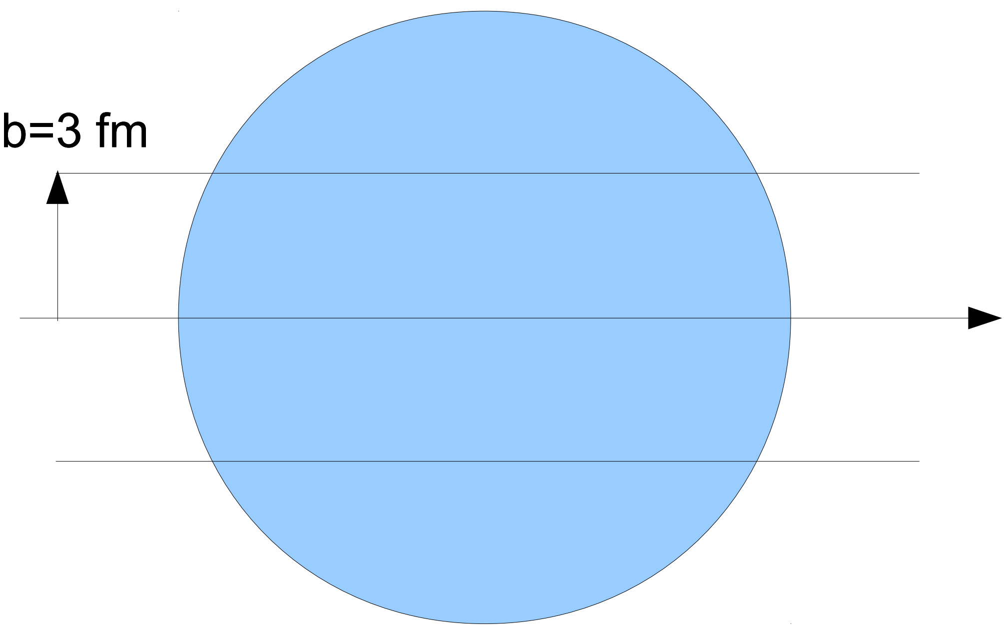
FY2018???

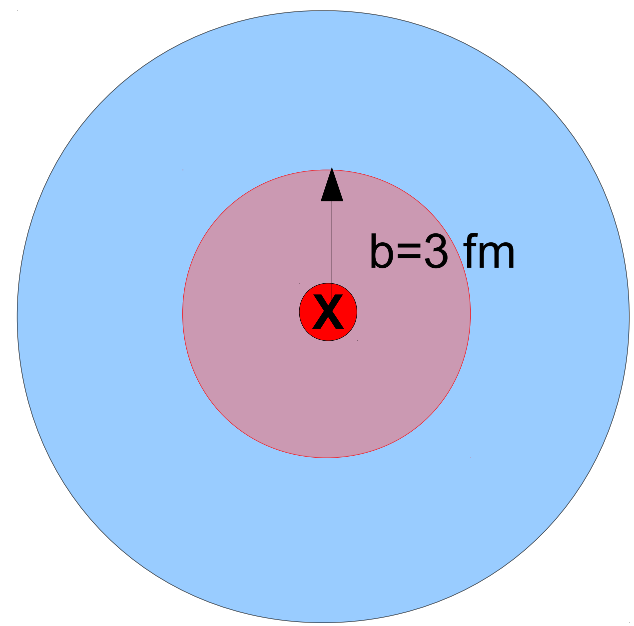
Summary

- Nuclear shadowing effects are imporatant!
  - Observing saturation is a key physics goal.
  - Geometry tagging sensitive to shadowing.
- Our eA DIS models don't handle it!
- Need to fix this NOW
  - IR design is ongoing at eRHIC & JLEIC.
  - Team with the exact MC expertise is in place.
- Extremely cost-effective.
  - Short-term project.
  - High Impact.

Extras

Note: b=3fm is still quite central!





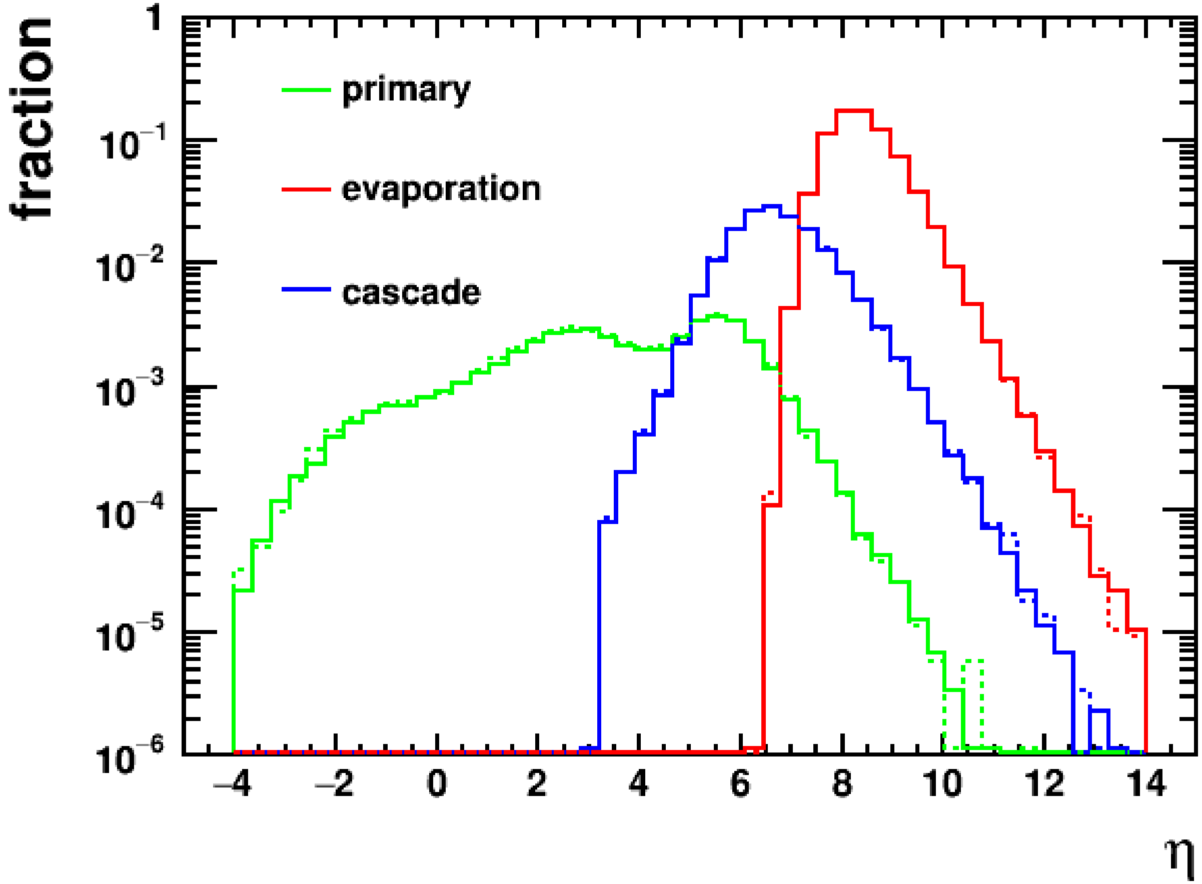
Hard sphere – half-height radius for Au: R=6.38 fm

Thickness @ b=3fm = 88% of max.

σ(b<3fm)/σ(total) = 29.5% (no shadow)
25.5% (R=0.711)

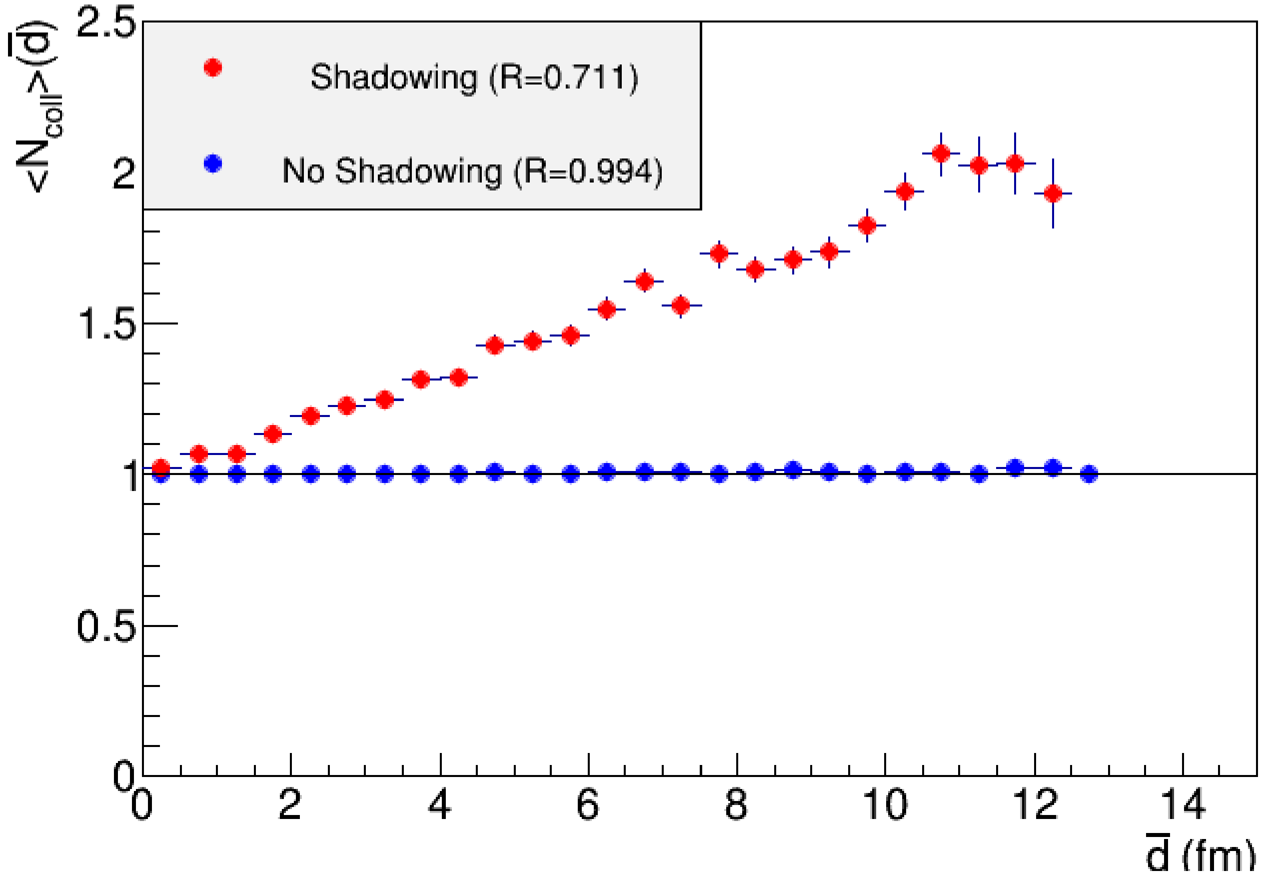
Impact of PARP(91)=k_T^{rms}

Solid: 0.24 GeV **Dotted: 0.11 GeV**



Modest changes in PARP(91) are barely visible.

Ncoll($\bar{d}$) for Q^2=1.69 GeV^2,x<<1

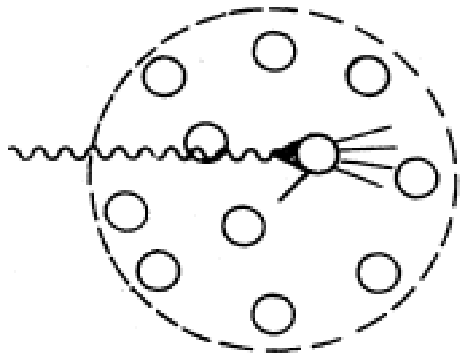


eA: Basic Quantum Mechanics

$\hbar=c=1$ $r=0.88$ fm $1/(2Mr) = 0.12$ $\Delta p_z \Delta z = 1/2$

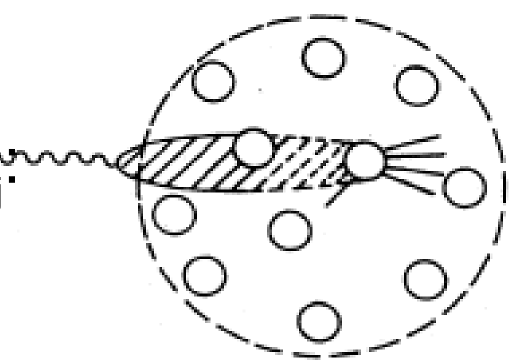
Bauer, Spital, Yennie, Pipkin
Rev. Mod. Phys. 50 (1978) 261

High x_{Bj}:



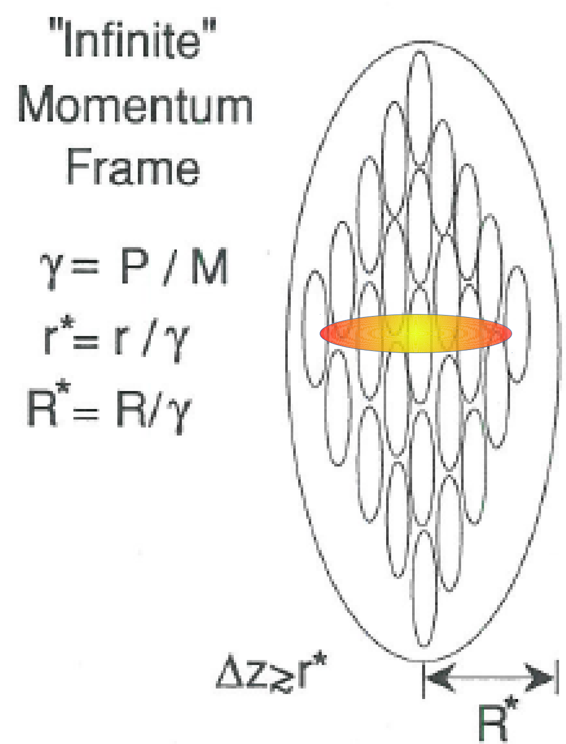
Nucleus Rest Frame (b)

Low x_{Bj}:



(c)

$\boxed{\lambda_h/r \approx 1/(2Mxr) = 0.12/x_{Bj}}$



$p_z^{quark} = Mx\gamma$

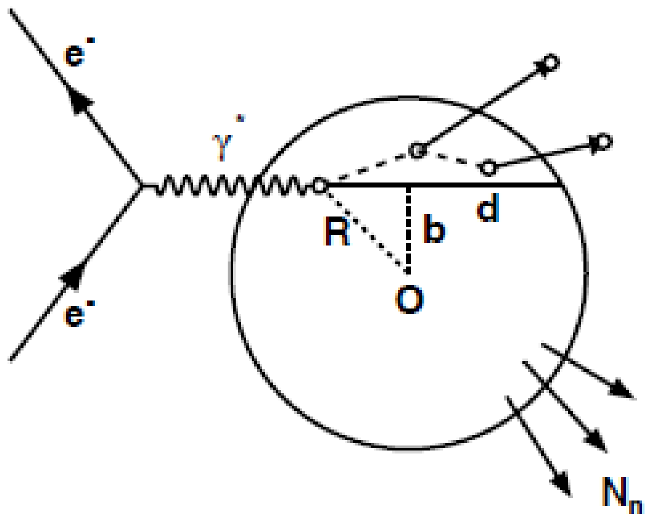
$\Delta z = 1/(2Mx\gamma)$

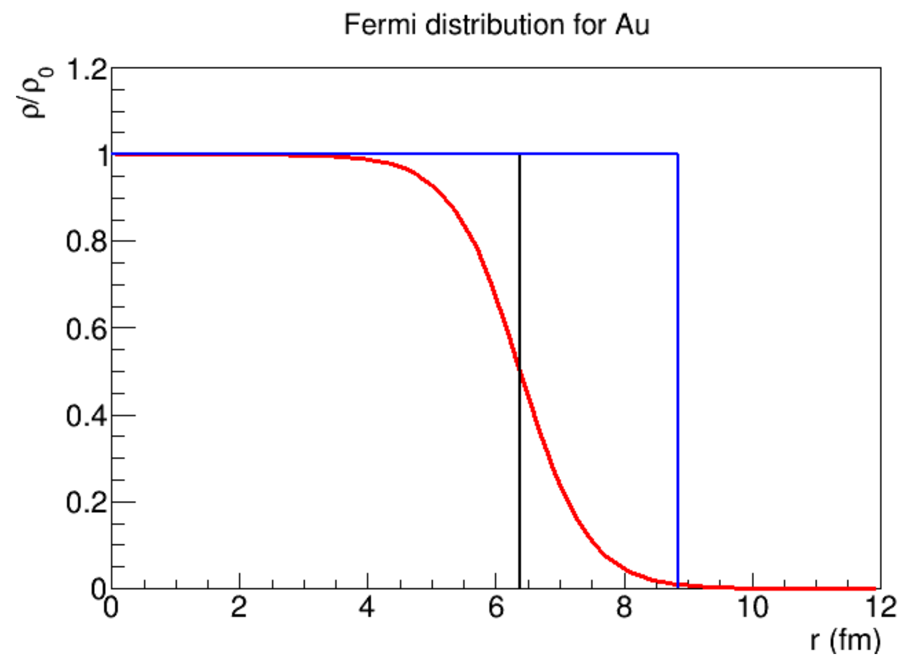
$$\boxed{\begin{aligned}\Delta z/r^* &= 1/(2Mxr)\\ &= 0.12/x_{Bj}\end{aligned}}$$

For x_{Bj}<<0.12, parton wavefunctions and/or interaction cannot be localized.

A ~~tale~~ tail of 3 d's

What do we mean by this circle?





Black line is R (hard-sphere approximation): leads to **$d=d_{hs}$**

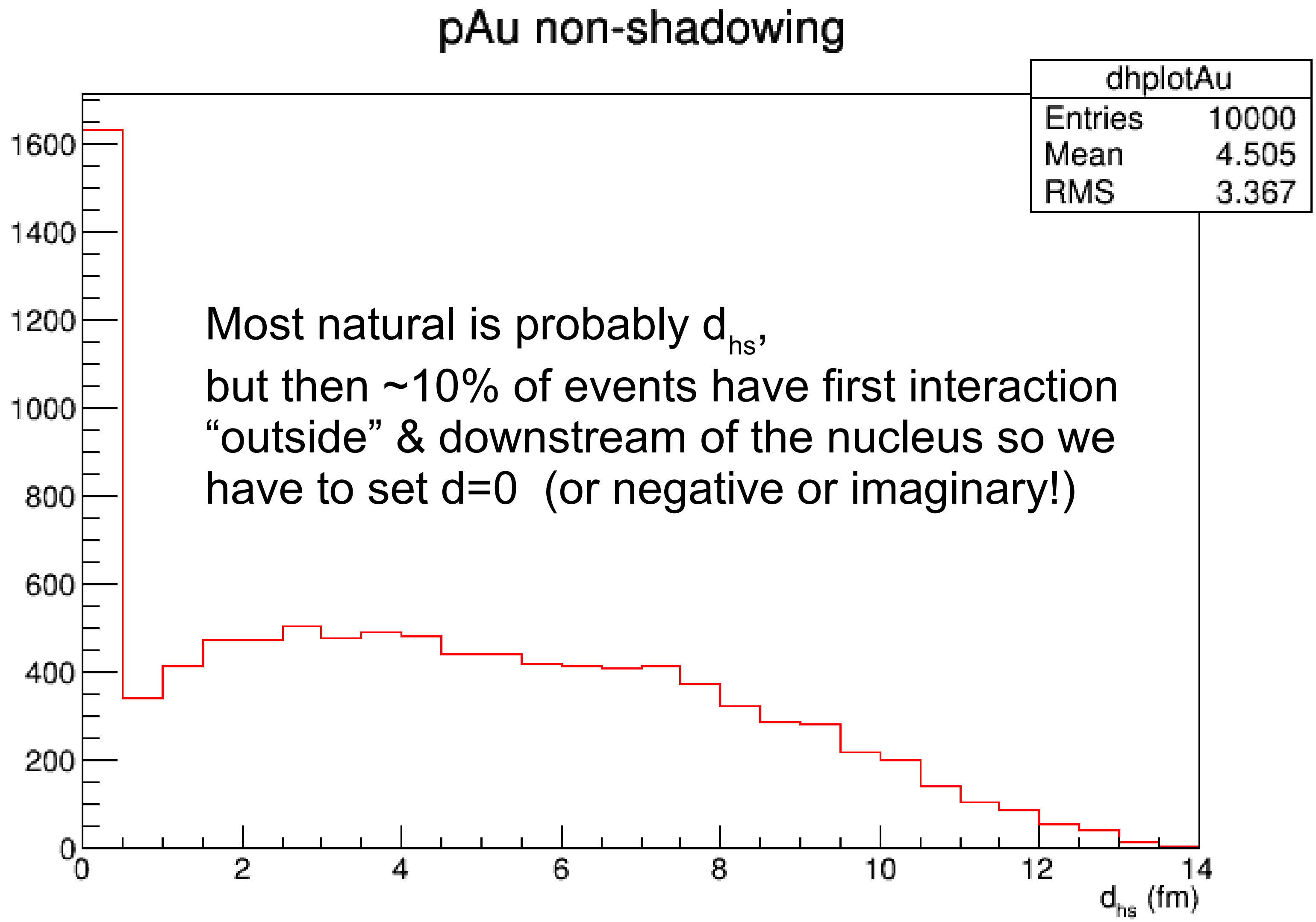
Blue line is $R_{edge}=R+a*\ln(100)$ (edge approx., used by ZAL): leads to **$d=d_{edge}$**

Red curve is actual matter distribution.

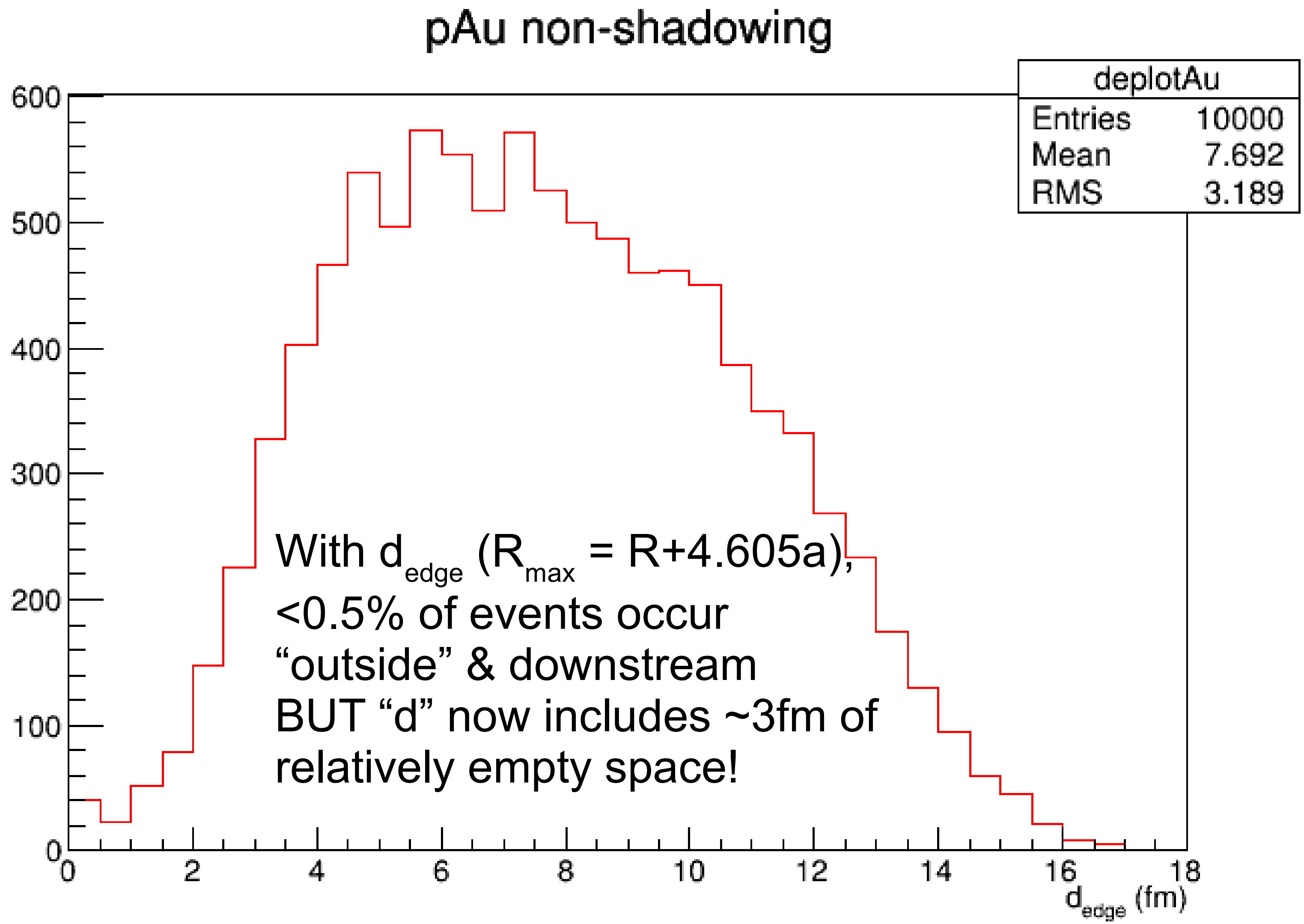
Define $\bar{d} \equiv \int dz\, \rho/\rho_0$ w/ integral from $Z_{first\text{-}collision} \rightarrow \infty$

Note: First collision at center of nucleus leads to $\bar{d} \approx d_{hs}=R_{Au}=6.38$ fm

Problems with hard edges I



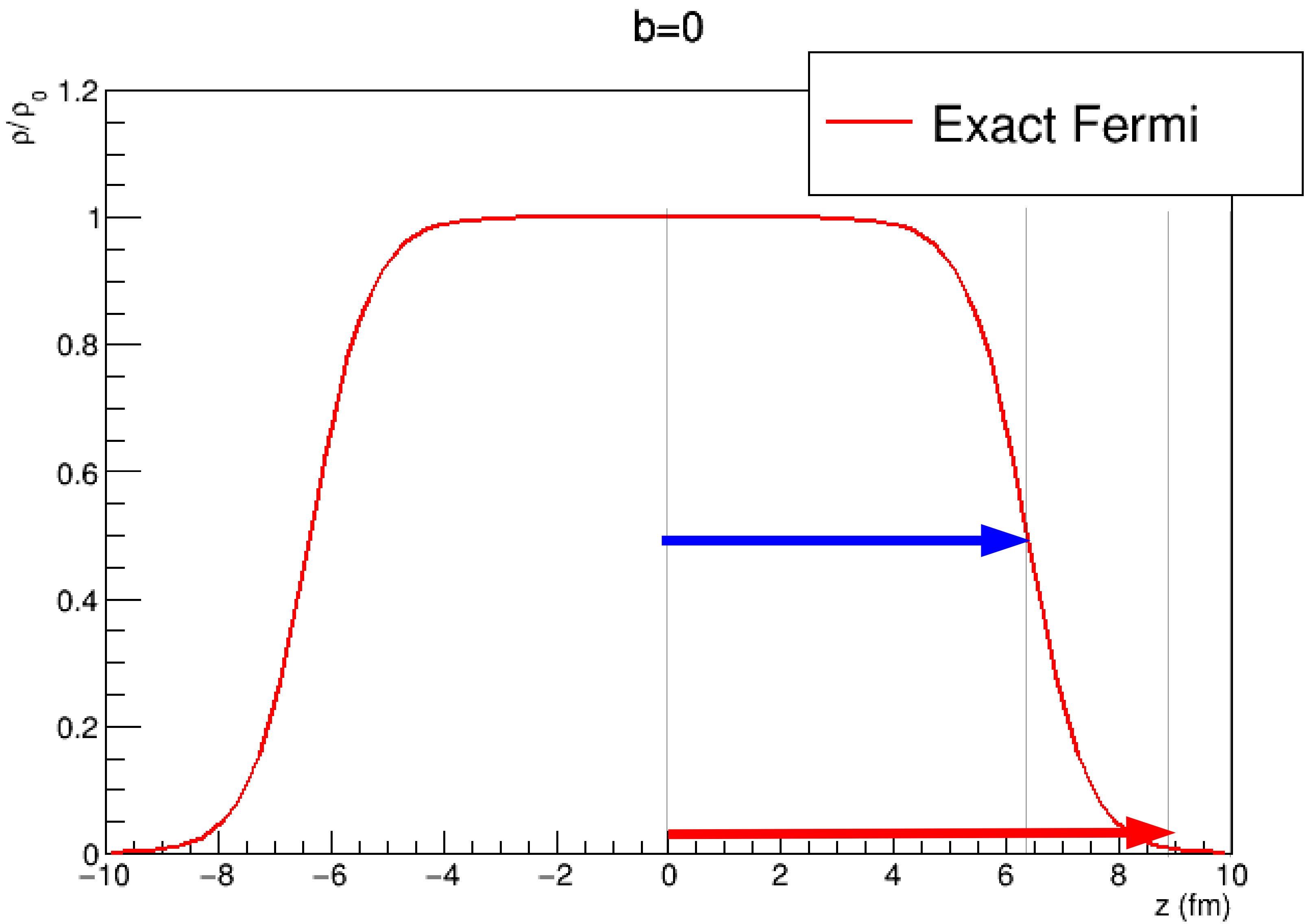
Problems with hard edges II



With d_{edge} (R_{max} = R+4.605a),
<0.5% of events occur
“outside” & downstream
BUT “d” now includes ~3fm of
relatively empty space!

$\rho/\rho_0 = \{ 1 + \exp[(r-R)/a] \}^{-1}$

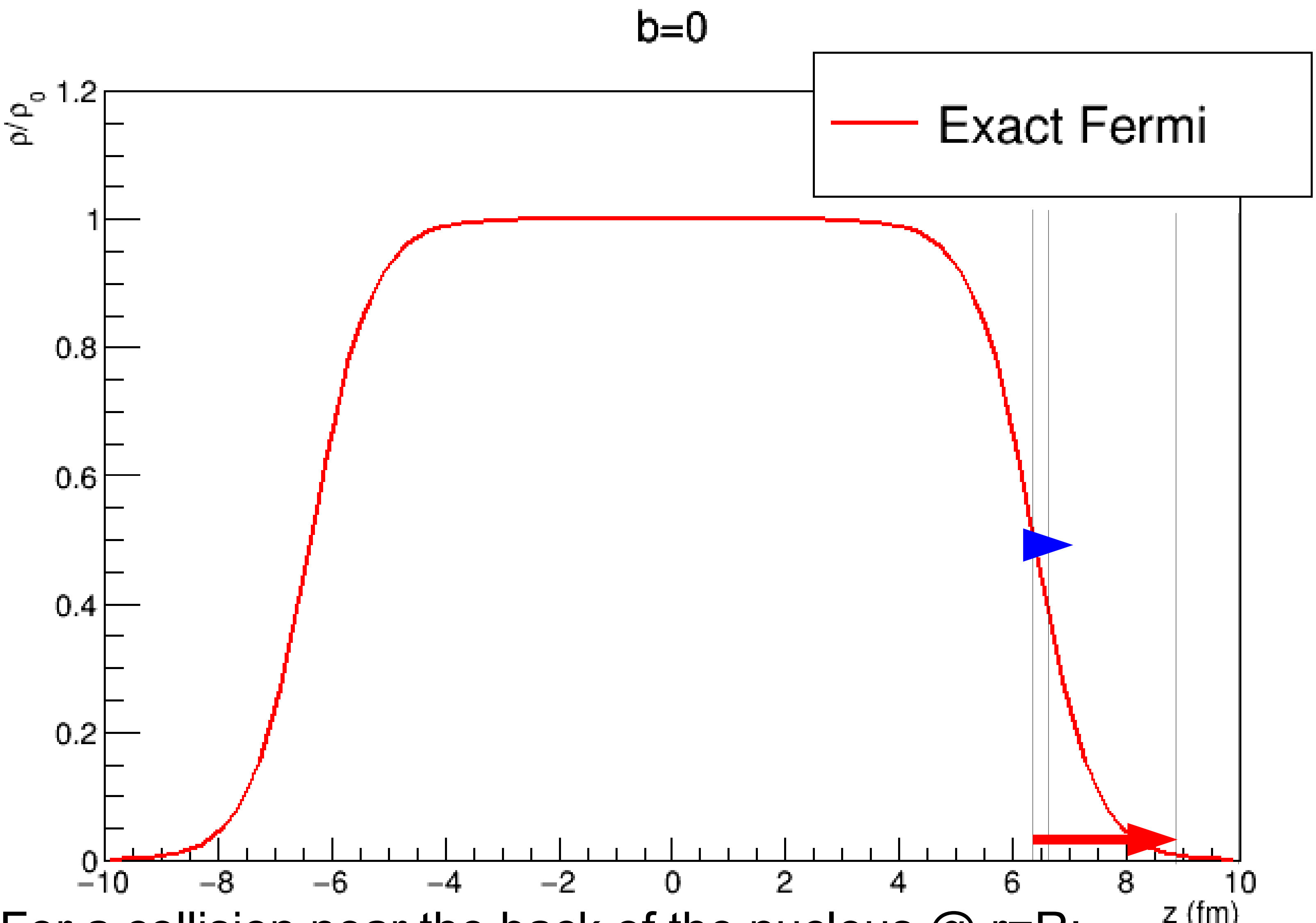
Note: $r^2 = b^2 + z^2$



For a collision in the center of the nucleus:

d_{hs} = R = 6.38fm while d_{edge} =R_{max} =8.844fm (for my WS-params)

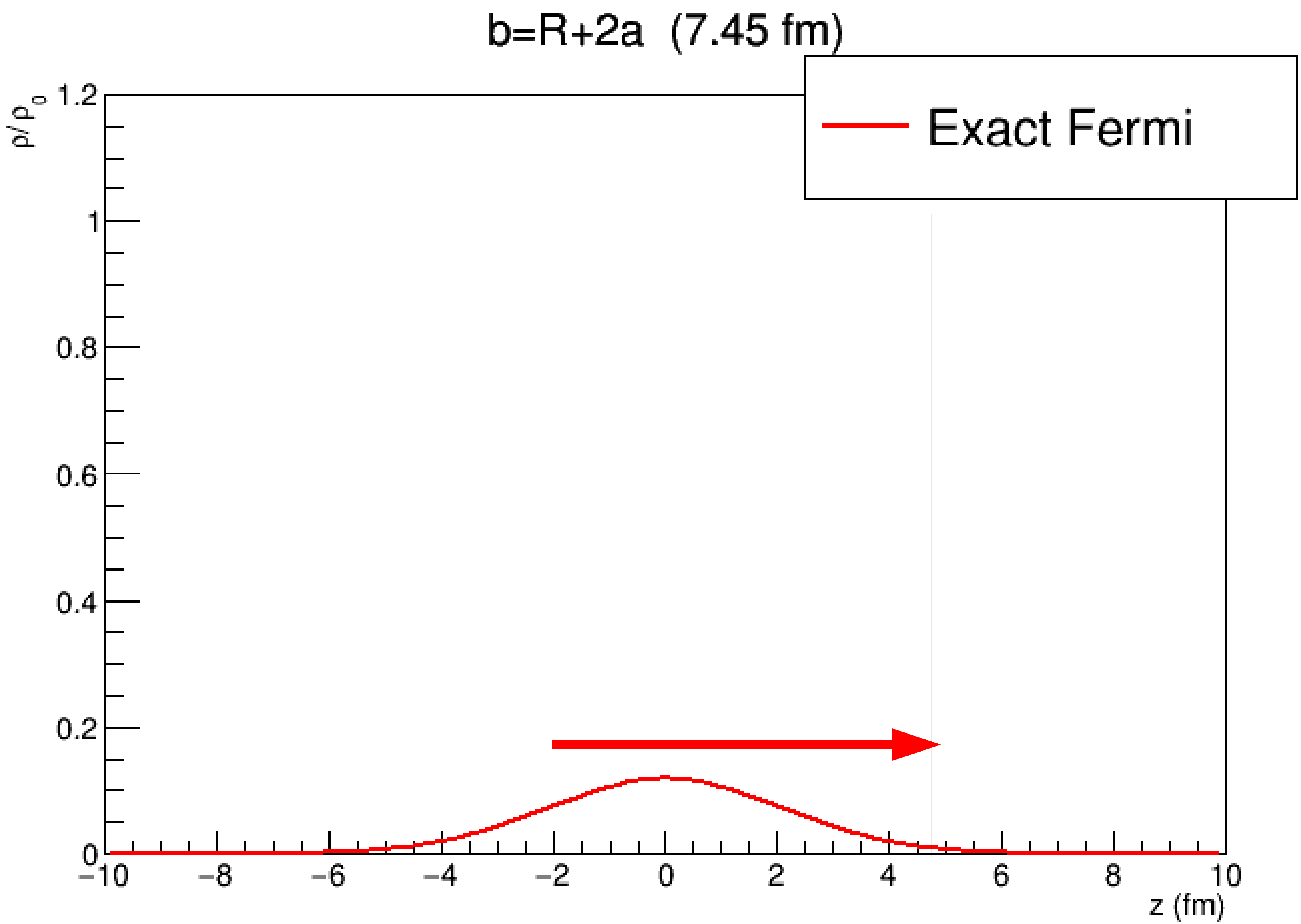
d_{edge} counts a lot of nearly empty space as part of the nucleus.



For a collision near the back of the nucleus @ r=R:

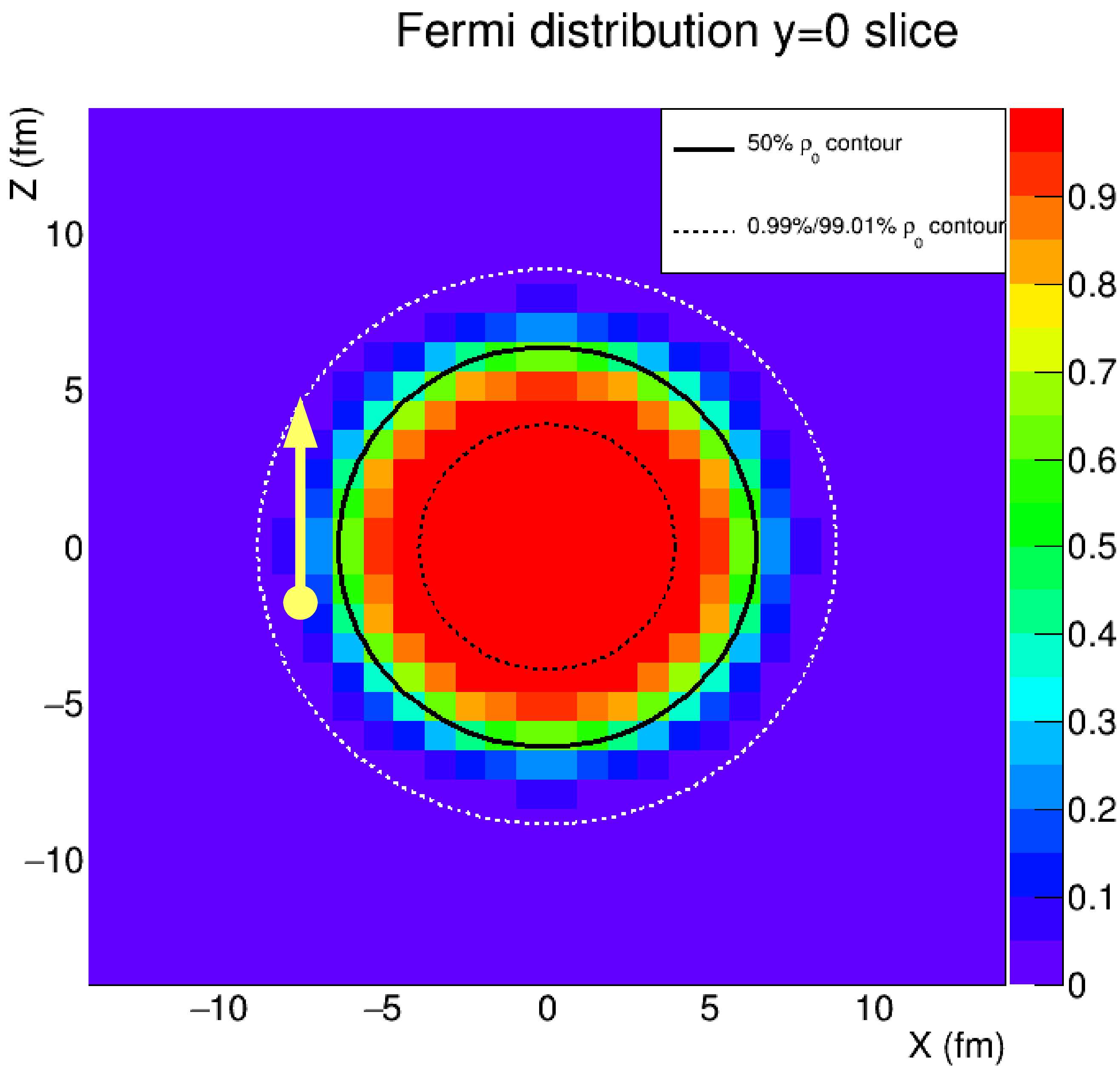
$\bar{d}$ = a ln2 = 0.37fm while d_{hs} = 0, d_{edge}=R_{max}-R=4.605a=2.46fm

Collision at Z= -2fm b=R+2a=7.45fm

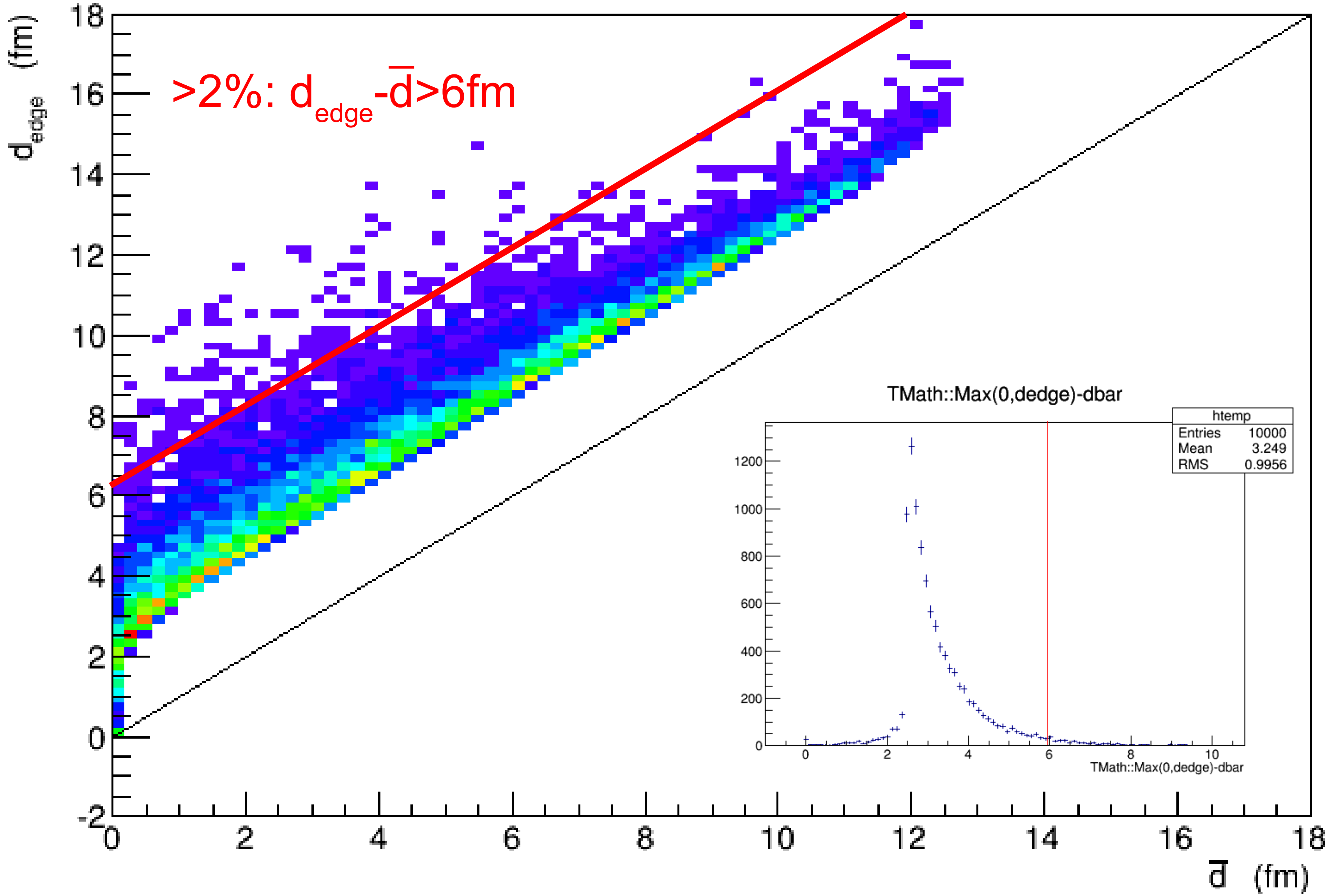


d_{edge}=6.77 fm **(>R!)** with almost NO material! $\bar{d}$=0.525 fm, d_{hs}=0

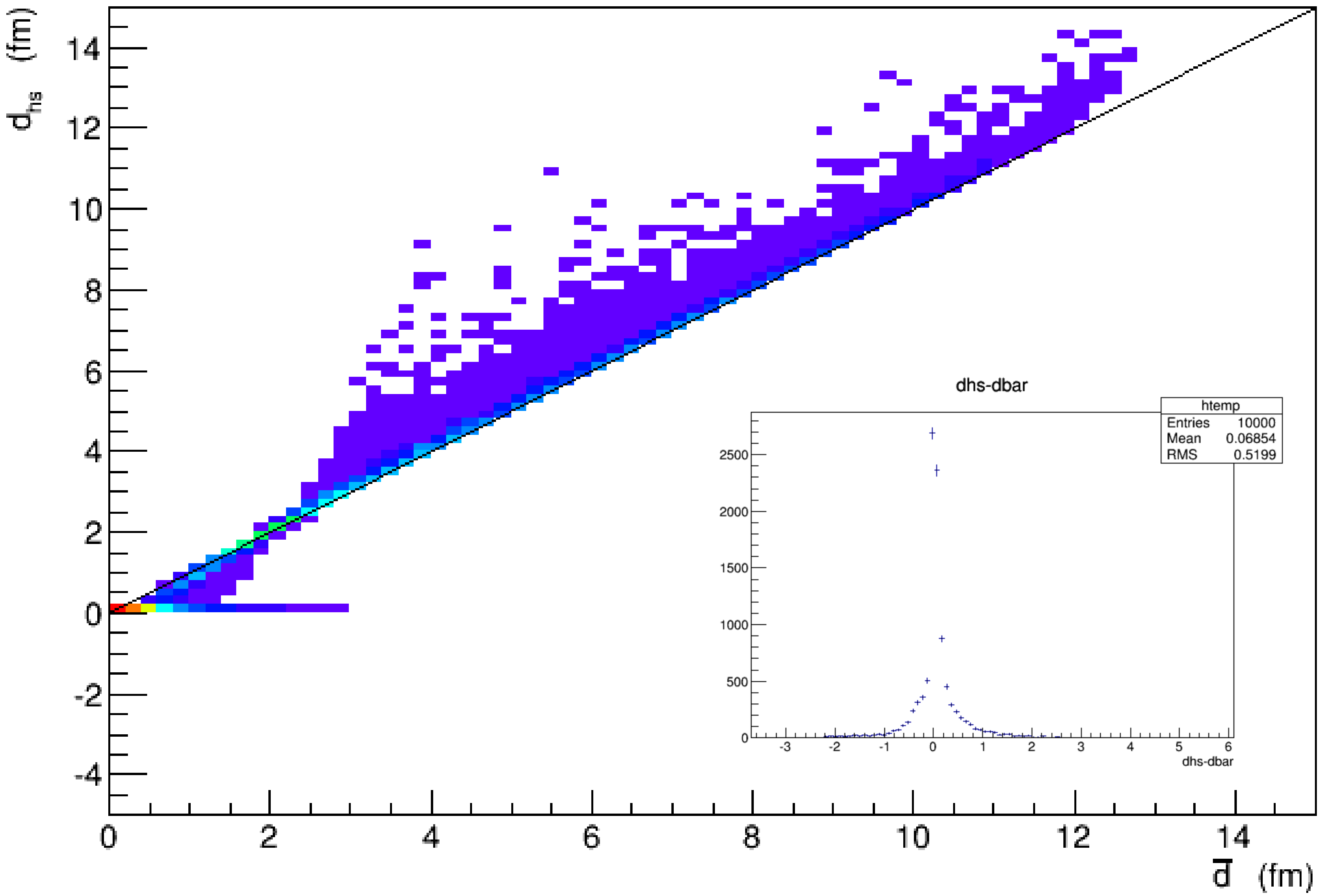
Trajectory for previous slide.



Comparison of d_{edge} and $\bar{d}$ for Au using TGlauberMC

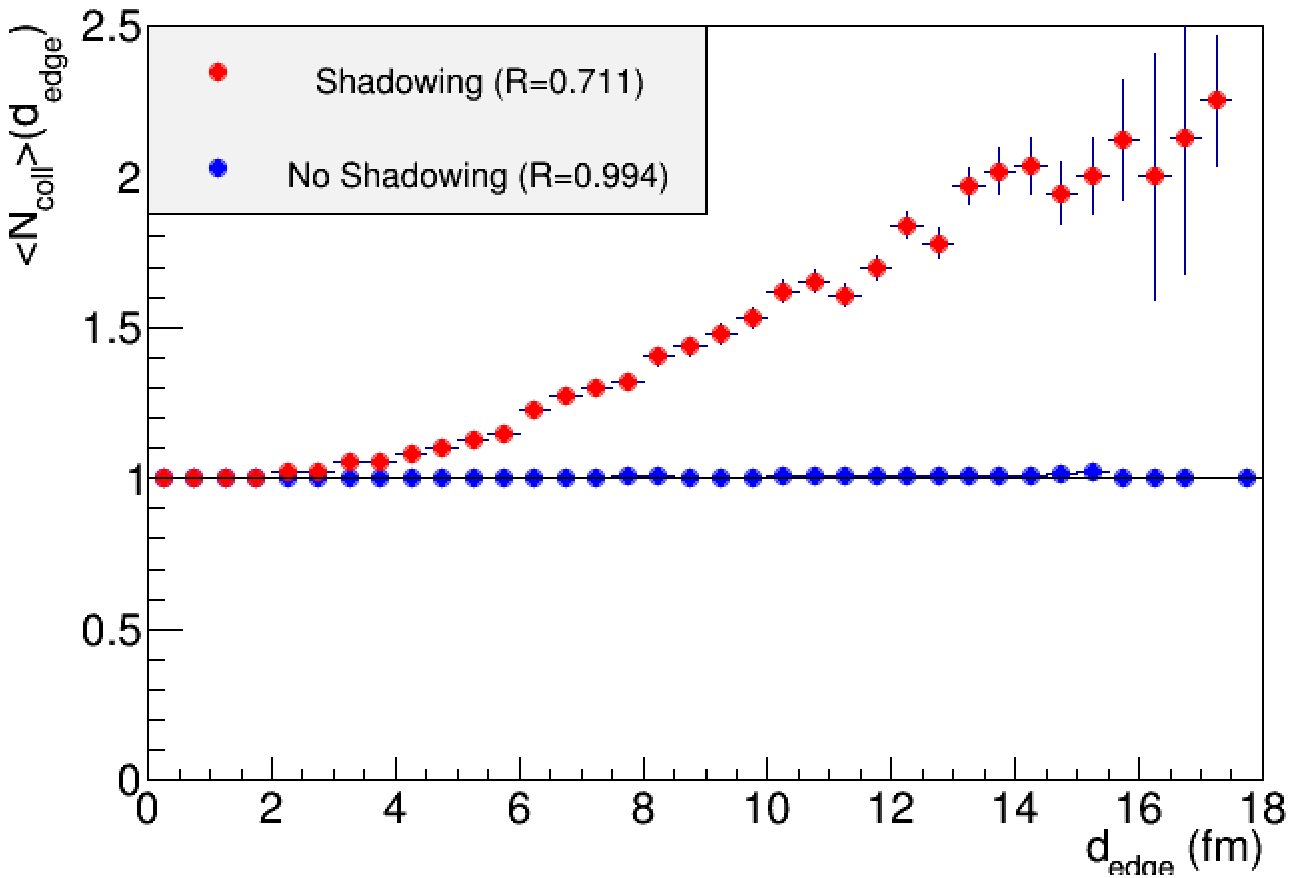


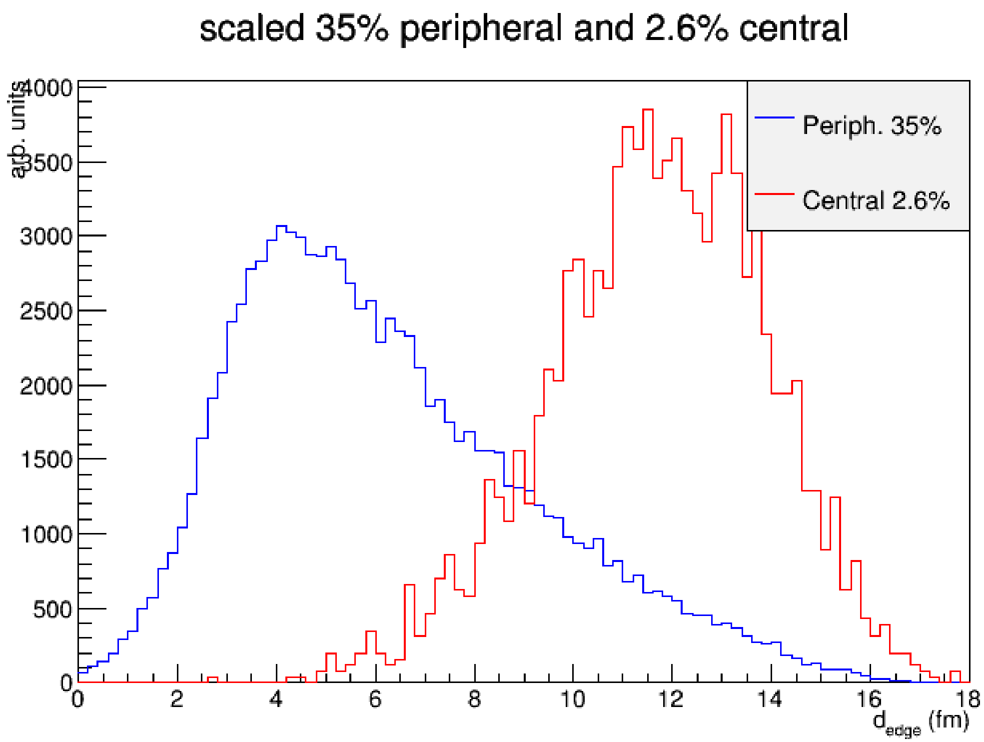
Comparison of d_{hs} and $\bar{d}$ for Au using TGlauberMC



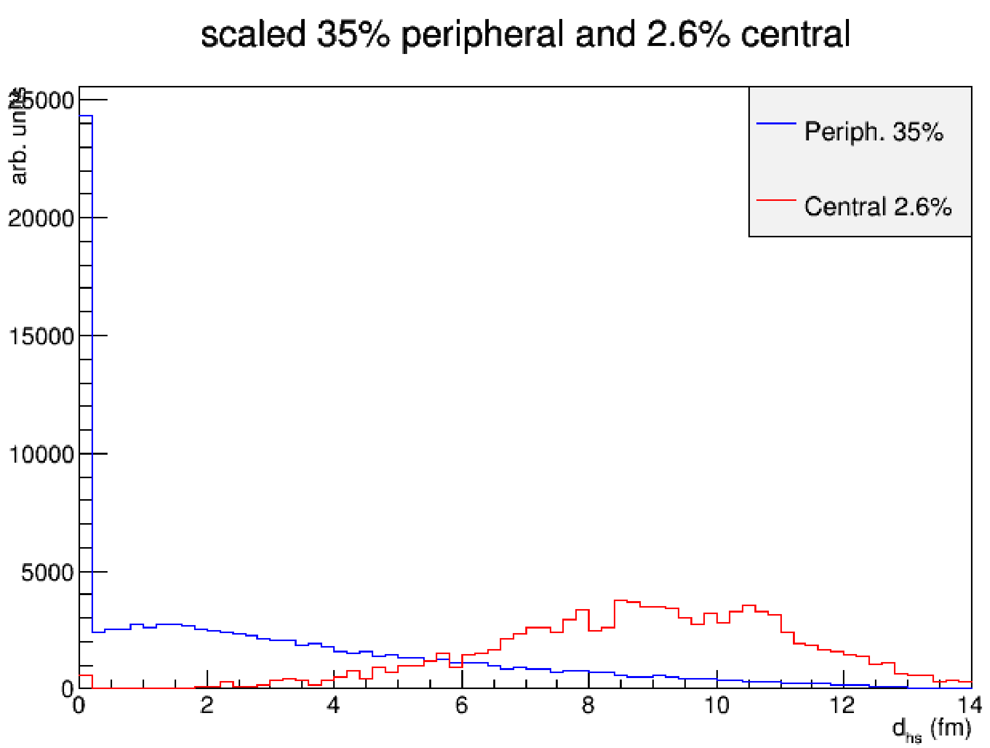
Ncoll(d_{edge}) for Q^2=1.69 GeV^2,x<<1

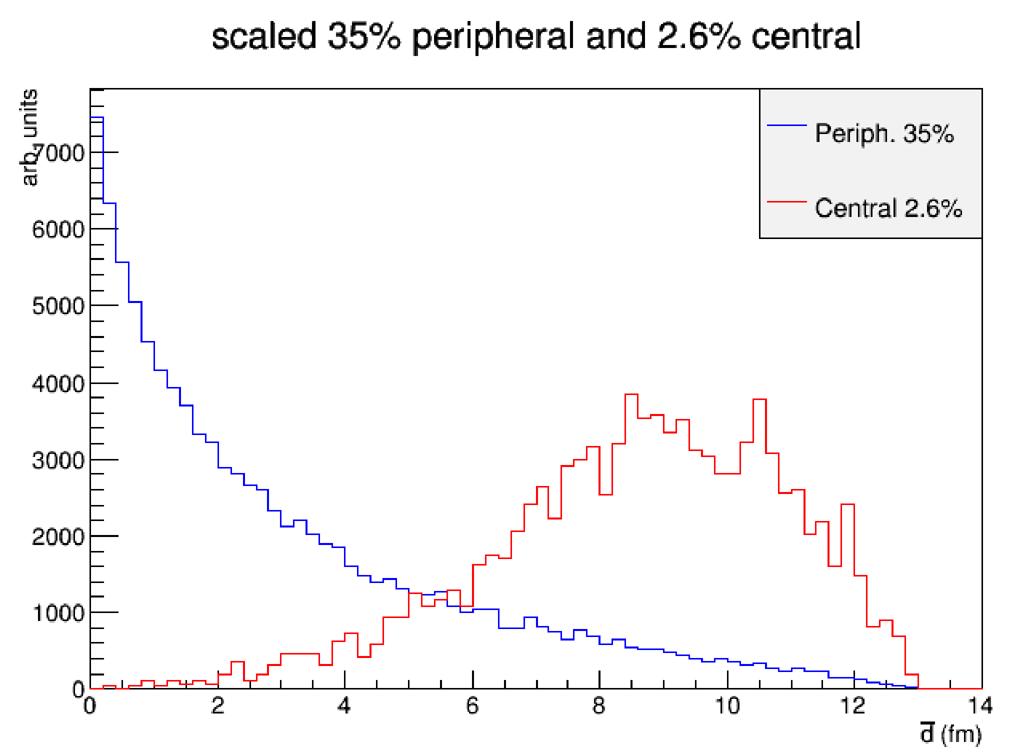
$F_2^A/F_2^N(x,Q^2)$ ⟷ $\sigma_{dipole}(x,Q^2)$ ⟷ $P(N_{coll},b)$





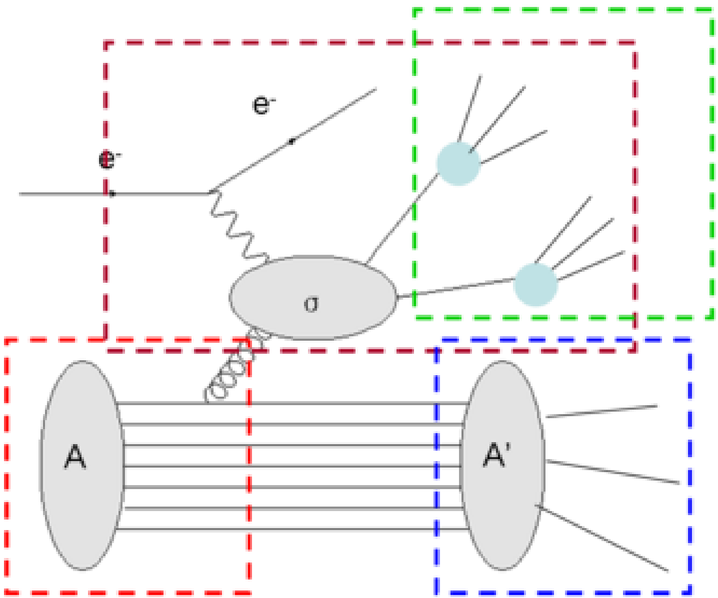
d distributions for 2 bins
for 3 definitions of d
Using DPMJetHybrid
PARP(91)=0.24 tune
Scaled to same area.





What about eA? DPMJet-Hybrid (1.0)

From: https://wiki.bnl.gov/eic/index.php/DpmjetHybrid



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet

Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

"One thing to be mentioned for the case to run PYTHIA in DPMJET is that only **one nucleon in the nucleus** will be picked as a target nucleon in the collision."

If valid, looking for Q_s in eAu would be easy. Just measure k_T recoil in ep & eAu.